Pathways of Effects (PoE) model development for capelin conservation as part of a risk analysis process

Noémie Giguère, Louise Perreault, Pierre Nellis, Claude Savenkoff, Francis Bilodeau, Martine Giangioppi, Gilles H. Tremblay, Réjean Dufour, Sophie Comtois and François Grégoire

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The purpose of the first phase of this pilot project was to create Pathways of Effects (PoE) models for capelin conservation in the Estuary and Gulf of St. Lawrence as part of a risk analysis process. When conducting this type of analysis, the PoE is created during the identification and problem formulation phase, the goal being to identify the potential relationships that exist between human activities, the stressors generated, and their impacts on a component of the ecosystem, and consequently on the communities that depend on this component. This project is related to the current national work on risk analysis and applies the theoretical notions established in the earlier work in the context of a real situation. In this context, capelin conservation in the Estuary and Gulf of St. Lawrence was identified for this project, since capelin is a key species in the marine food chain. During this phase, six PoE models were developed, each illustrating one view of capelin conservation that is either general or specific. Together, these models serve illustrate the relationships that exist between the ecological, socio-economic, and cultural components as well as such key ecological parameters as the quantity and quality of capelin spawning / larval retention habitat and capelin abundance. The development and application of PoE models using a real situation have confirmed their usefulness as tools for integrating knowledge and for communication; PoEs also play a role in providing support for decision-making and guidance for subsequent steps in the risk analysis process.

RÉSUMÉ

Giguère, N., Perreault, L., Nellis, P., Savenkoff, C., Bilodeau, F, Giangioppi, M., Tremblay, G.H., Dufour, R., Comtois, S. et Grégoire F. 2011. Réalisation de modèles de séquence des effets (SdE) appliqués à la conservation du capelan dans le cadre d'une approche d'analyse de risque. Rapp. tech. can. sci. halieut. aquat. 2934 : vii + 76 p.

La première phase de ce projet pilote visait la création de modèles de séquence des effets (SdE) appliqués à la conservation du capelan de l'estuaire et du golfe du Saint-Laurent, à l'intérieur du cadre d'analyse de risque. Lors d'une telle analyse, la SdE est créée à l'étape d'identification et de formulation de la problématique afin d'identifier les liens potentiels existant entre les activités humaines, les facteurs de stress générés et leurs impacts sur une composante de l'écosystème et, par conséquent, sur les collectivités qui en dépendent. Le présent projet vient s'annexer aux travaux nationaux réalisés sur le sujet de l'analyse de risque et vise à appliquer les concepts théoriques établis par ceux-ci à une situation réelle. Pour ce faire, le sujet de la conservation du capelan de l'estuaire et du golfe du Saint-Laurent a été retenu, puisque le capelan est une espèce clé dans le réseau trophique marin. Au cours de l'exercice, six modèles SdE ont été élaborés. Ils illustrent chacun une vision soit générale, soit spécifique du contexte de la conservation du capelan. L'ensemble des modèles permet d'obtenir un portrait des liens existants entre les volets écologique, socio-économique et culturel et les paramètres écologiques d'importance que sont la

quantité et la qualité de l'habitat de fraie et d'alevinage du capelan et l'abondance du capelan. La création de modèles et leur application à un cas réel (conservation du capelan) ont permis de confirmer l'utilité des SdE en tant qu'outil d'intégration des connaissances et de communication, en plus de confirmer leur rôle de support à la prise de décision et de guide pour les étapes subséquentes de l'analyse de risque.

1.0 INTRODUCTION

Risk[1] analysis and Pathways of Effects (PoE) models are decision-making assistance tools that support managers and practitioners involved in different levels of planning, notably in the areas of integrated ocean management and ecosystemic management.

Risk analysis is an approach used by several national and international institutions (e.g., Queensland Environmental Protection Agency in Australia, United States Environmental Protection Agency, Canadian Food Inspection Agency, and Food and Agriculture Organization of the United Nations). To fulfil one Department of Fisheries and Oceans (DFO) mandate, which is to "study, conserve and protect aquatic ecosystems" (DFO 2008a), risk analysis has been identified as a key process leading to improved management of the impacts generated by human activities[2] on aquatic components and ecological functions. Risk analysis generally includes various steps: *identification* and *problem formulation*, *risk assessment*, and *risk management* (Figure 1).

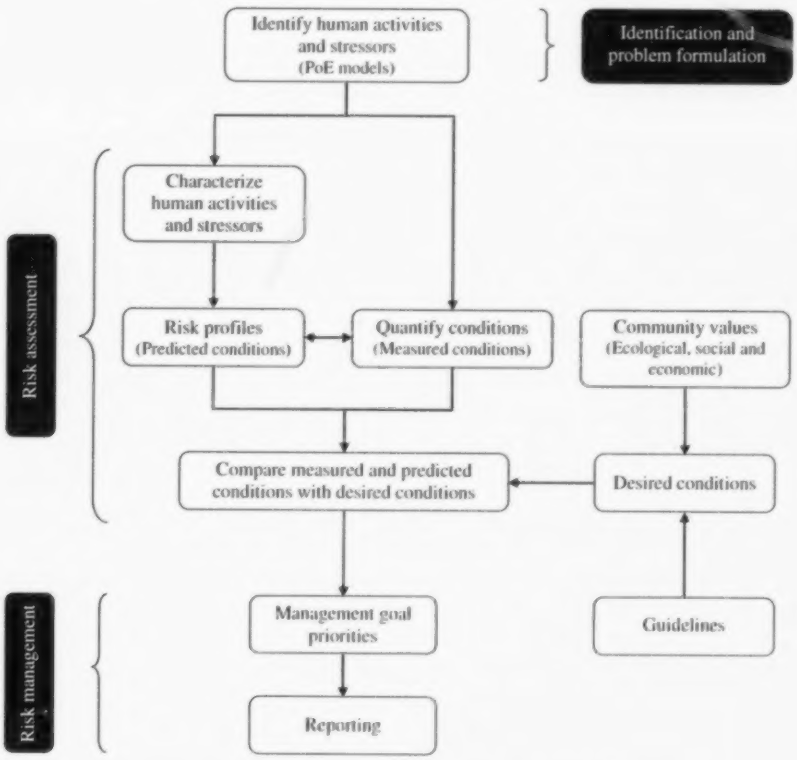

Figure 1. Steps in the risk analysis process (adapted from Moss et al. 2006).

[1] Risk can be defined as the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (U.S.-EPA, 1998).
[2] The term *human activity* has been selected for this report but *driver* is also currently used in literature. The definition is provided in Appendix 2.

As for the Pathways of Effects model, it is a more specific conceptual tool that can be used in a variety of contexts, but which is particularly pertinent within a risk analysis: it contributes to the identification and the ploblem formulation phase of the process in addition to serving as the foundation for the subsequent steps. More specifically, the PoE illustrates and documents the potentials cause-and-effect relationships between some socio-economic, cultural, community, and ecological aspects of a given problem. Thus, the models can portray the relationships existing between human activities and their potential ecological impacts. They serve to reveal which industries and communities depend on the resource and also to identify the industries that could be affected by the implementation of resource conservation or protection measures.

At DFO, PoE models were initially developed to address the needs of the Habitat Management Program, the goal at the time being to guide fish habitat managers when assessing the risks associated with certain projects (DFO 2006, DFO and NRIA unpublished[3]). In 2008, a Pathways of Effects national working group was created by the DFO Oceans Directorate. The work of this group was to facilitate and harmonize the development and application of PoEs when dealing with environmental problems in the aquatic environment, and this work served to draw up national guidelines for preparing Pathways of Effects models (DFO in prep.[4]).

This project, headed by the Oceans Management Branch – Quebec Region, is attached to the national work and applies the theoretical notions established in the earlier work in the context of a real situation. Phase I of this project focuses on the production of PoE models, the first step in the risk analysis process. The goal is to validate the usefulness of the tool by applying theoretical principles to a real situation and adapting the development of the models to situational requirements. In a second phase, the risk assessment step will be dealt with, taking the structure of the PoE models developed here as the starting point. In order to carry out this entire project effectively and ensure the pertinence of its results, the study subject of the risk analysis effort had to occupy a place of importance in the St. Lawrence ecosystem. Capelin (*Mallotus villosus*) was thus selected as the target species for this pilot project because of its ecological importance in the food chain (Savenkoff et al. 2007a, 2007b) and its distribution throughout the Estuary and Gulf of St. Lawrence (Grégoire et al. 2008). During this first phase, the Pathways of Effects models will serve to illustrate some of the human impacts on capelin habitat and capelin populations as well as on the communities that depend on capelin to gain a greater understanding of associated potential issues.

A working group was set up (Appendix 1) to develop PoE models, which were grouped into two categories: holistic or specific models. While the holistic model offers a view of all the relationships that exist between human activities and capelin conservation, each of the specific models—five in this document—shows greater detail by focusing on a specific element of the subject.

[3] DFO (Department of Fisheries and Oceans) and NRIA (National Resource Industry Associations). Unpuplished. A guideline to prepare best management practice to streamline DFO's approval process. Version 1.0/2006. 18 pp.
[4] DFO (Department of Fisheries and Oceans). In preparation. Draft Pathways of Effects National Guidelines: January 25th.

2.0 METHODOLOGY

The guidelines proposed by DFO (in prep.) lay down the foundation for the methodology that was used. A number of the concepts and definitions presented in this section were drawn from or inspired by those guidelines. At times, PoE model development for the specific case of capelin required the adaptation of existing methodologies. The complete methodology is presented in this section, and it includes a conceptual description of the Pathways of Effects models, the description of the objective of capelin conservation, the definition of the study area, and the data collection context.

2.1 PATHWAYS OF EFFECTS MODELS

A PoE is defined as a conceptual representation (based on facts) of the predicted relationships between human activities and the stressors[5] and impacts they can have on a specific ecological or biological component (DFO in prep.). Altering a component of this kind can, in return, have consequences on the "goods and services" provided by the ecosystem (definition in Appendix 2) and ultimately, on socio-economic or cultural activities and values.

The products associated with a PoE are (i) a schematic representation of the relationships that illustrates the situation being studied and (ii) a literature-based document describing the PoE. Pathways of Effects models can be adapted to different contexts and needs. They can take several forms depending on the subject being discussed and the manner of dealing with it. Consequently, the models can be more or less complex depending on the scale (local, regional, or national) for which the model is being built and the degree of detail that will be included. The important factors to consider when developing PoE models include the number of relationships depicted, the comprehensiveness of the information, the prediction's precision, the certainty surrounding each linkage, and the potential for measurement (DFO in prep.).

2.1.1 Description of the holistic model

The holistic model provides an overview of a situation by limiting the number of details, which helps keep the focus on identifying the human activities that are present in a geographical unit, on the stressors arising from these activities, and on the societal and ecosystem elements associated with the subject. Another advantage of this type of model is that it shows the number of activities and interactions that are possible in this sector and in doing so draws attention to the potential cumulative effects on the ecosystem and its components.

The holistic model produced for capelin conservation is presented in Section 3.1. To produce the PoE diagram, a series of terms and symbols was selected to adequately represent the entire context. The design of the symbols was inspired either by existing DFO models (in prep.) or developed in keeping with a similar logic. These terms and symbols are presented in Appendix 2.

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[5] The word *stressor* has been chosen for this report, but *pressure* is also used in others references. In this report, a *stressor* has a human origin as opposed to a *natural stressor*, which is provoked by environmental conditions. The Appendix 2 provides definitions for stressor and natural stressor.

2.1.2 Description of specific models

While the holistic model presents a global view of a context, the specific (or detailed) models exist to highlight the particularities or complexities of a situation. The DFO document (in prep.) identifies two main types of specific models: *endpoint* models and *activity/action and sector-based* models. The decision as to which of these types of models to use depends on the goals and objectives of a given analysis. For this project, the endpoint model was chosen.

Endpoint models are structured from the top down and focus on a particular parameter, such as an ecosystem component or an ecosystem service that needs to be protected (DFO in prep.). Endpoint models can (i) identify sectors and stressors that may impact ecological components and ultimately a species (e.g., species-based model); (ii) identify all potential consequences of the alteration of ecological components on social, cultural, and economic values (socio-economic and cultural models); or 3) identify only the pressures that may impact ecosystem components (e.g., stressor-based models) (DFO in prep.).

As mentioned earlier, five specific models were created to focus more closely on certain aspects of the subject that call for a more detailed view. These specific models are divided into two categories: specific ecological models and specific socio-economic and cultural models (presented in Sections 3.2 to 3.6). Here also, a series of terms and symbols was selected to create the diagrams. Their design and the related terminology were either modelled on existing DFO models (in prep.) or developed in a manner that would harmonize with the former (Appendix 2).

2.2 ENDPOINT

Since capelin was chosen as the target species, the context and characteristics specific to this species were taken into consideration when producing the various PoE models. A review of knowledge pertaining to capelin biology was conducted to provide a scientific base for the process. Then, the ecological component to be valued, which will be known as the *endpoint* in the context of the pilot project, was defined. The endpoint and the life cycle of the species are described in the following sections.

2.2.1 Definition of the endpoint

Capelin is a highly important link in the food chain since it serves to transfer energy from the primary and secondary producers (phytoplankton and zooplankton) that it feeds on to the species higher up the food chain (finfish and marine mammals) that prey on it (Savenkoff et al. 2007a). Given this ecological importance and the possible contacts between the species and certain human activities, particularly in inshore areas where its spawning / larval retention area is located (see Section 2.2.2), *capelin conservation* in the Estuary and Gulf of St. Lawrence was identified as the endpoint.

The capelin conservation objective used for this project is based on the work of the Gulf of St. Lawrence Integrated Management (GOSLIM) conservation objective development workshop (DFO 2007a). In the workshop, capelin was put on a preliminary list of priority species to be considered for the eventual development of conservation objectives pertaining to species of

ecological significance in the St. Lawrence marine ecosystem. Although these species and their associated conservation objectives were not validated in the workshop (DFO 2007a), a preliminary objective can be formulated using the criteria by which capelin can be considered a species of ecological significance (a forage species). Hence, "*To ensure that capelin (Mallotus villosus) is not disturbed by human activities to the point where it can no longer fulfill its role as a key element in the ecosystem's food chain*" (M. Gilbert and R. Dufour, DFO, pers. comm.) will be used as the capelin conservation's objective for this project. This objective occupies a central place within the PoE models produced.

Furthermore, the general objective formulated for the 10 ecologically and biologically significant areas (EBSAs) in the Estuary and Gulf of St. Lawrence (DFO 2009) can be adapted to the project requirements in order to highlight the importance of certain areas (habitats) for species conservation; this general objective is to "ensure that the characteristics that make the area suitable for aggregation and/or that the reproduction and survival of dependent species in the area are not altered by human activities." On-going GOSLIM work may help establish the capelin conservation objective more firmly in the future if capelin is recognized as a species of ecological significance as part of a formal scientific review on the subject.

2.2.2 Capelin life cycle

Capelin is a small pelagic fish that spends most of its life at sea and moves to the coast for spawning. Its range is circumpolar, and it is found in the northwest Atlantic, along the coasts of Labrador and Newfoundland, and on the Grand Banks as well as in the Estuary and Gulf of St. Lawrence (DFO 2008b). Capelin lives only a few years, with few individuals living longer than four years (Stergiou 1991, Mowbray 2002). Sexual maturity is reached at around two or three years of age. However, the spawning stock is almost exclusively composed of three- and four-year-old fish (Jangaard 1974).

Egg deposition, which occurs primarily on beaches and in shallow water, generally takes place at night or on overcast days (Jangaard 1974) when water temperatures range from 6 to 10°C (DFO 2008b). The spawning period generally lasts from four to six weeks. According to Grégoire (2004), it begins first in the St. Lawrence Estuary around mid-April and gradually moves eastward, occurring in July along Québec's Lower North Shore and the west coast of Newfoundland. However, unpublished data collected over the last ten years by the Capelin Observers Network (CON) indicates that spawning may occur simultaneously in the Estuary and Gulf.

When spawning, capelin separate into two schools depending on their sex. The male school swims closer to the beach and the female school farther offshore. When the females are ready to lay their eggs, they head in to the beach where they are joined by the males (Jangaard 1974). When females and males meet, they swim side by side and make their way as close to the beach as possible, where they rapidly dig furrows in the loose sediment with their fins and tails and try to bury the eggs as deeply as possible. The surf also helps bury the eggs in the substrate. After spawning, most males die (nearly 100%) and only a few females survive (DFO 2008b). Natural mortality is very high, which can cause the abundance of populations to fluctuate widely and leave this species sensitive to other sources of mortality from year to year.

The eggs are reddish in colour and about 1 mm in diameter. They settle on the gravel on the beach or on the seabed. Incubation time varies according to water temperature; it lasts 15 days on average when the water temperature is 10°C (Jangaard 1974). Upon hatching, the larvae measure from 3 to 6 mm in length. They then become pelagic and remain near the surface until winter (DFO 2008b). Thereafter, they move to deeper water until the water warms up in the spring (Jangaard 1974). Templeman (1948; cited in Jangaard 1974) observed that capelin larvae measure from 2 to 4 cm in length at the beginning of winter. At around one year of age, capelin is considered juvenile and has reached 8 cm in length. At maturity, the females range in size from 15 to 17 cm and the males vary from 17 to 19 cm in length (Jangaard 1974).

2.3 STUDY AREA

The project's study area is the Estuary and Gulf of St. Lawrence (Figure 2).

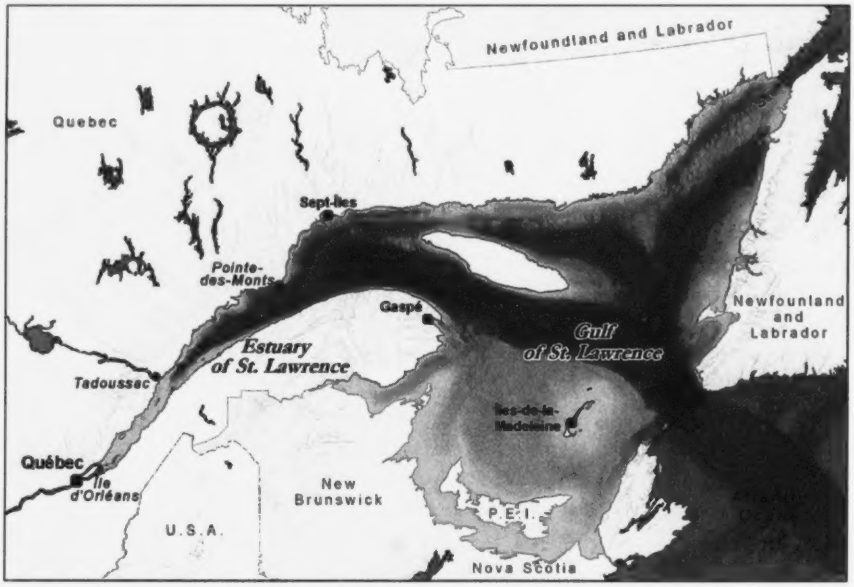

Figure 2. Image of the Estuary and Gulf of St. Lawrence showing their limits (red lines) and the region's main bathymetric characteristics (Source: Fish Habitat Management Information System – FHAMIS, DFO).

2.4 DATA COLLECTION

The steps taken while collecting data aimed first of all to gather general information on the biology of the species, as mentioned in Section 2.2; then, the goal was to determine what elements of the anthropogenic context would be retained to produce the models. During this step, a number of elements were selected and documented to describe the potential relationship existing between each one and capelin conservation. The different categories of PoE elements studied include measurable endpoints, socio-economic and cultural dependencies, aquatic

ecosystem goods and services, human activities, human and natural stressors, human and natural modulating factors, impacts, socio-economic and cultural consequences, scientific advice, and the affected industries. Each of these PoE element categories is defined and discussed in greater detail in the glossaries (Appendices 2 and 3).

Finally, it is important to point out that there are very few studies documenting the impacts human activities have on capelin in the Estuary and Gulf of St. Lawrence. Most of the information found dealt with studies on capelin conducted in other regions of Canada or elsewhere in the world or on related species that may or may not be present in the Estuary and Gulf of St. Lawrence. Also, data collection led to the observation that the current scientific knowledge about capelin is highly fragmentary, particular with respect to its biology and abundance, the spawning and larval retention areas, and the environmental factors influencing its annual migrations and natural variability. For example, there is no systematic survey to measure the abundance of the capelin stock in the Estuary and Gulf of St. Lawrence, and there are major knowledge gaps regarding the number, location, and size of capelin spawning grounds (Grégoire et al. 2008). Taken together, these knowledge gaps increased the level of uncertainty of the data collected; consequently, identifying and characterizing relationships between the various PoE elements is more complex. Wherever the data were incomplete and when pertinent, expert opinion was considered. Thus, the PoEs produced are the result of an interpretation and synthesis of the available information and a consensus reached among the working group participants. The quality and quantity of information available to justify the connections between the elements presented in the models have therefore influenced the results outlined in the next section.

3.0 RESULTS

The PoE models applied to capelin conservation follow the theoretical concepts outlined in Section 2.1. Occasionally some adjustments were required to adapt the model to the unique characteristics of the real situation and to the requirements of the stakeholders and decision makers involved with this resource. In the models where there was some deviation (adjustments) from theory (outlined in Sections 3.2 to 3.6), the parts of the diagrams that represent the conventional PoE are shown inside a grey line and elements outside this line represent the previously mentioned adjustments. These may be contextual elements (e.g., human modulating factors) or operational elements (e.g., formulating scientific advice) that can influence or be connected to elements of the conventional PoE.

Sections 3.1 to 3.6 outline the six PoE models developed as part of the project. For each model, the first subsection outlines and describes the elements of the model and the primary information used to justify the elements' inclusion in the PoE. The second subsection provides a description of potential connections and an interpretation of the model (key points, strengths, and weaknesses).

To facilitate understanding, readers are advised to consult the following:

1. for the holistic model: the holistic model glossary (Appendix 3) and the definitions and sample PoE elements (Appendix 2)

2. for the specific ecological models: the glossaries for the specific ecological models (Appendix 4) and the holistic model (Appendix 3) as well as the definitions and sample PoE elements (Appendix 2)
3. for the specific socio-economic and cultural models: the glossaries for the specific socio-economic and cultural models (Appendix 5) and the holistic model (Appendix 3) as well as in Appendix 2 for the definitions and sample PoE elements.

3.1 HOLISTIC MODEL FOR CAPELIN CONSERVATION

3.1.1 Presentation of the model and its main elements

Figure 3 shows the diagram for the holistic Pathways of Effects model for capelin conservation. This overview serves to identify 11 activity sectors present in the Estuary and Gulf (e.g., municipal activities and fisheries) that can potentially influence the endpoint. The two main stressors (alteration of the coastal area[6] and biomass removal) that can generate impacts on the aquatic ecosystem goods and services and on the socio-economic and cultural activities that depend on it are also shown. The main elements of the model are described below.

3.1.1.1 Human activities and socio-economic and cultural dependencies: eleven activity sectors are present or may be present in the study area in the short or medium term. For instance, the renewable energies field does not appear here because there are no projects involving the establishment of wind farms in the marine environment, nor are any being considered for the time being. Each of these activities is associated with at least one of the stressors identified.

3.1.1.2 Stressors: two principal stressors linked to human activities and able to affect capelin conservation have been identified: alteration of the coastal area[5] and biomass removal. Anthropogenic causes of coastal alteration can originate either on land or at sea. As for biomass removal, it represents the capture (generally in terms of weight) of a fish stock or a fraction of a fish stock (Ricker 1980).

3.1.1.3 Measurable endpoints: measurable endpoints establish the link between the endpoint and the identified legislative, international, management, conservation, or recovery objective. A measurable endpoint should adequately reflect the management goal and the ecosystem it represents. Measurable endpoints will aid the operationalization of the objectives (DFO in prep.). Multiple measurable endpoints related to capelin conservation exist, but only two of these were selected for their relevance to the project objectives (i) the quantity and quality of capelin spawning / larval retention habitat[7] and (ii) capelin abundance. These two allow the identification of most potential stressors and impacts of human activities on capelin and its conservation.

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[6] Note: "Alteration of the coastal area" is a category of stressors that can potentially negatively affect coastal areas. Creating this category simplifies the holistic model diagram. The stress factors constituting the "Alteration of the coastal area" category are identified individually in the specific ecological model in Section 3.2.

[7] To make the text easier to read, the measurable endpoint "Quantity and quality of capelin spawning and larval retention habitat" will be referred to as "Spawning and larval retention area" for the rest of the document.

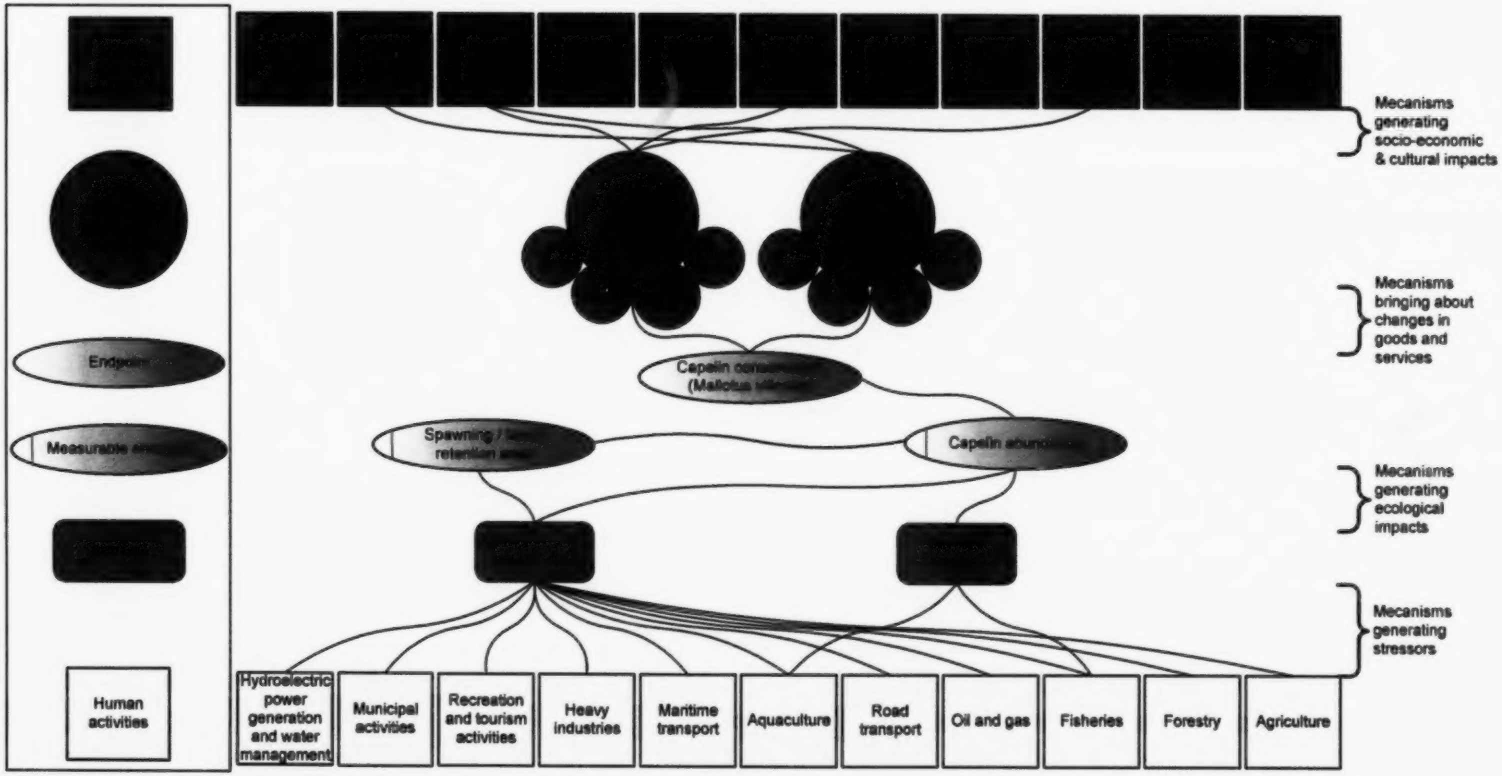

Figure 3. Holistic Pathways of Effects model for capelin conservation in the Estuary and Gulf of St. Lawrence.

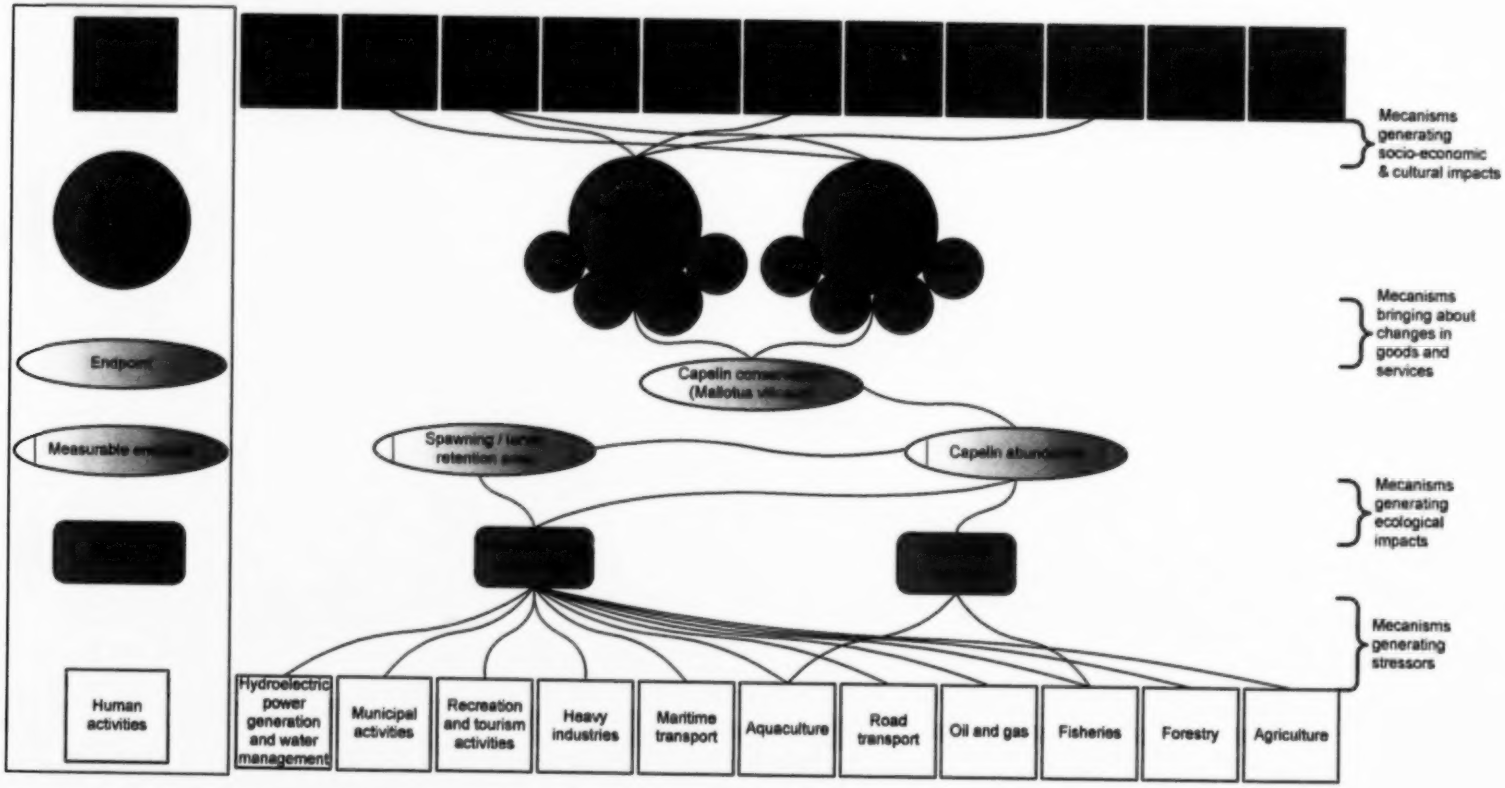

Figure 3. Holistic Pathways of Effects model for capelin conservation in the Estuary and Gulf of St. Lawrence.

3.1.1.4 Aquatic ecosystem goods and services: the goods and services provided by the aquatic ecosystem are various and can include several sub-categories. The DFO guidelines (in prep.) present an example of a holistic model that features the services proposed by the Millennium Ecosystem Assessment Working Group (MA 2005): supporting services, provisioning services, cultural services, and regulating services. In the context of capelin conservation, two of these—provisioning services and cultural services—have been retained.

3.1.1.5 Socio-economic and cultural dependencies: the activity sectors identified in Section 3.1.1.1 that are present or that have the potential to be present in the study area are not all dependent on the capelin resource. This category allows the clear identification of those dependencies.

3.1.2 Description and interpretation

The holistic model allows some general observations to be made about capelin conservation. The measurable endpoints appear to be interconnected. This can be explained by the possible effect of the quality of the spawning / larval retention area on the number of viable fry and eggs (capelin abundance). Another example of the interconnection between the measurable endpoints is that variation in the number of spawners could ultimately lead to variation in the number of spawning sites (rate of site occupation during the spawning period). Also, the model shows that most human activities could generate mechanisms able to provoke alteration of the coastal area while only aquaculture and the fisheries would induce significantly the *biomass removal* stressor. Finally, capelin could directly provide goods and services (provisioning or cultural) to four sectors of activity: aquaculture, fisheries, municipal activities, and recreation and tourism activities.

There are a number of advantages to the holistic model. It illustrates all the various activities present and their possible interactions with the endpoint. It also highlights the cumulative effects either on the ecosystem and its components or on the human activity sectors that depend on them or that could be affected by the implementation of measures to protect the species. This shows the range of ecological, socio-economic, and cultural repercussions connected to capelin conservation. The principal weakness of this model is the limited degree of detail presented, which reduces possibilities of interpretation.

3.2 SPECIFIC ECOLOGICAL MODEL FOR SPAWNING / LARVAL RETENTION AREA

3.2.1 Presentation of the model and its main elements

The model diagram presented in Figure 4 shows the stressors identified that constitute the *alteration of the coastal area* category: shoreline modification, modification of hydrological regime, modification of water temperature and/or salinity, modification in organic matter and/or nutrients input, and the introduction of contaminants. It also demonstrates the possible interconnections among the stressors and their potential impacts on measurable endpoints. These various stressors are described in Sections 3.2.1.1 to 3.2.1.5; additional information on these

stressors and their actions are provided in Appendices 6 and 7. Also included in this model is the scientific advice that characterize the measurable endpoint *capelin abundance* by assessing the status of the capelin stock in the Estuary and Gulf of St. Lawrence each year and by making recommendations for its preservation. Finally, the modulating factor *governance* was retained, notably to illustrate the potential effects that management measures can have on shoreline modification.

3.2.1.1 Stressor *shoreline modification*: since the capelin spawning / larval retention habitat is located primarily in the inshore area, any modification here could potentially affect capelin conservation. Concretely, changes in the level of the variables associated with erosion amplify the process of shoreline retreat (Savard et al. 2009). If erosion reduces beach width, this could also reduce the number of spawning sites and thus decrease capelin abundance. However, it is possible that the sediment generated by erosion processes could in turn contribute to supplying or enlarging (via accretion) some beaches suited for capelin reproduction.

On the other hand, human activities designed to limit the impact of the significant erosion and retreat of some beaches and cliffs (e.g., construction of protective structures, artificial beach replenishment) also modify the natural dynamic of the shoreline (e.g., accumulation of rocks or sediment) and potentially modify the spawning / larval retention habitat. Nakashima and Taggart (2002) showed that for capelin that spawn on beaches, sediment structure and size have a quantitative and significant influence on egg laying success Lastly, increasing the artificial nature of coastal areas (e.g., municipal, harbour, and road development) can be a source of stress for capelin habitat in the areas where it occurs. One concrete example of this type of modification or degradation is Ferguson Beach on the Gaspé Peninsula, which was almost entirely covered with rock, inducing erosion and a reduction in the size of the intertidal zone, to the point where capelin no longer use it to spawn (Hans-Frédéric Ellefsen, DFO, pers. comm.).

3.2.1.2 Stressor *modification of hydrological regime*: the development of certain life stages in fish is synchronized with seasonal variations in productivity and some environmental conditions, such as the hydrological regime. Hence, a change in these conditions can have impacts on fish development and potentially on their survival (Stalnaker et al. 1989). Most freshwater input to the Estuary and Gulf of St. Lawrence is from watersheds. One of the main sources of variation in freshwater flow anticipated in the coming years could be increased precipitation due to climate change (Dufour and Ouellet 2007). Changes in marine currents, mostly due to glacier melt, could also influence primary production and the migration of diverse marine species (Anderson and Möllmann 2004).

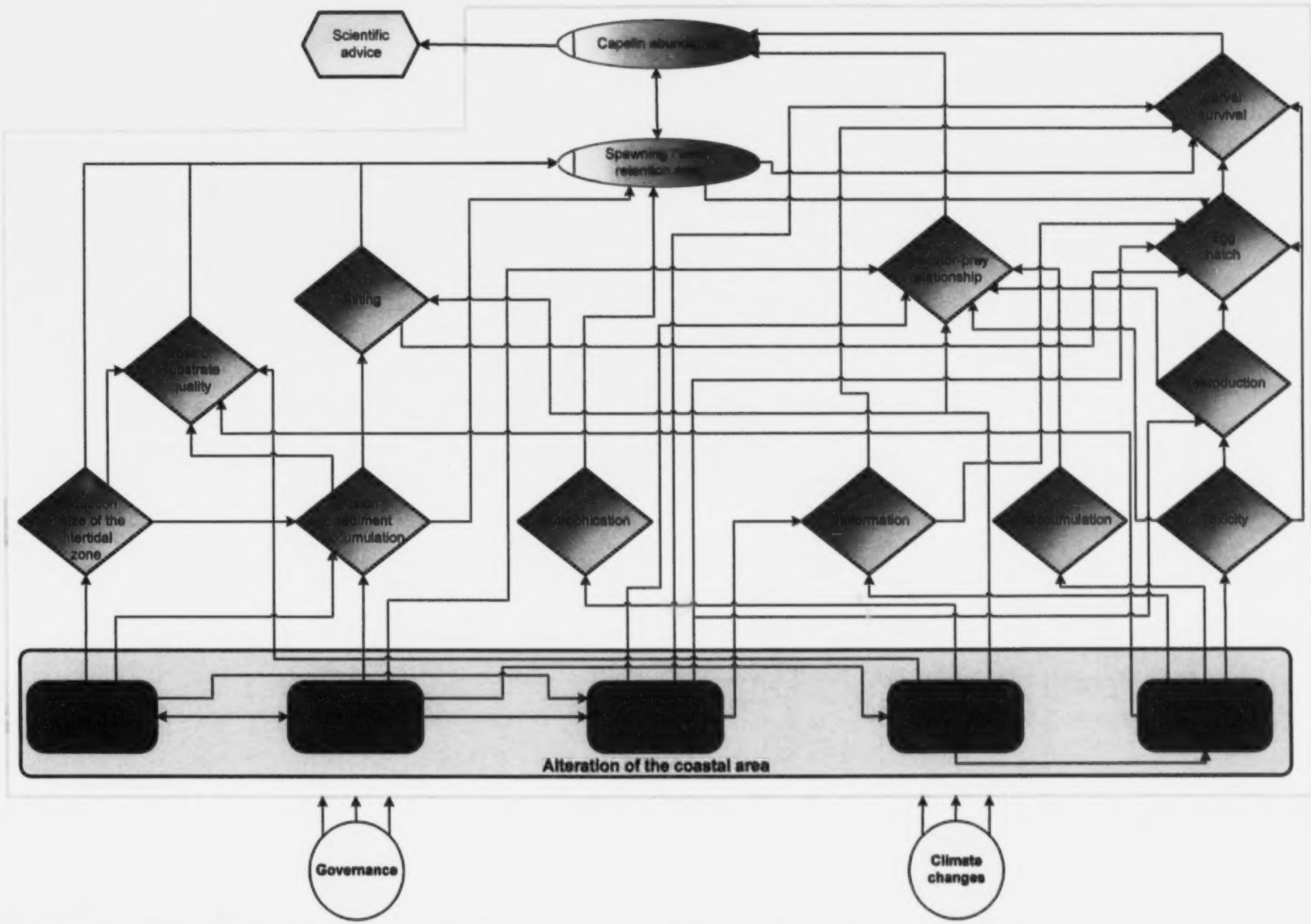

Figure 4. Specific ecological Pathways of Effects model for capelin spawning / larval retention area.

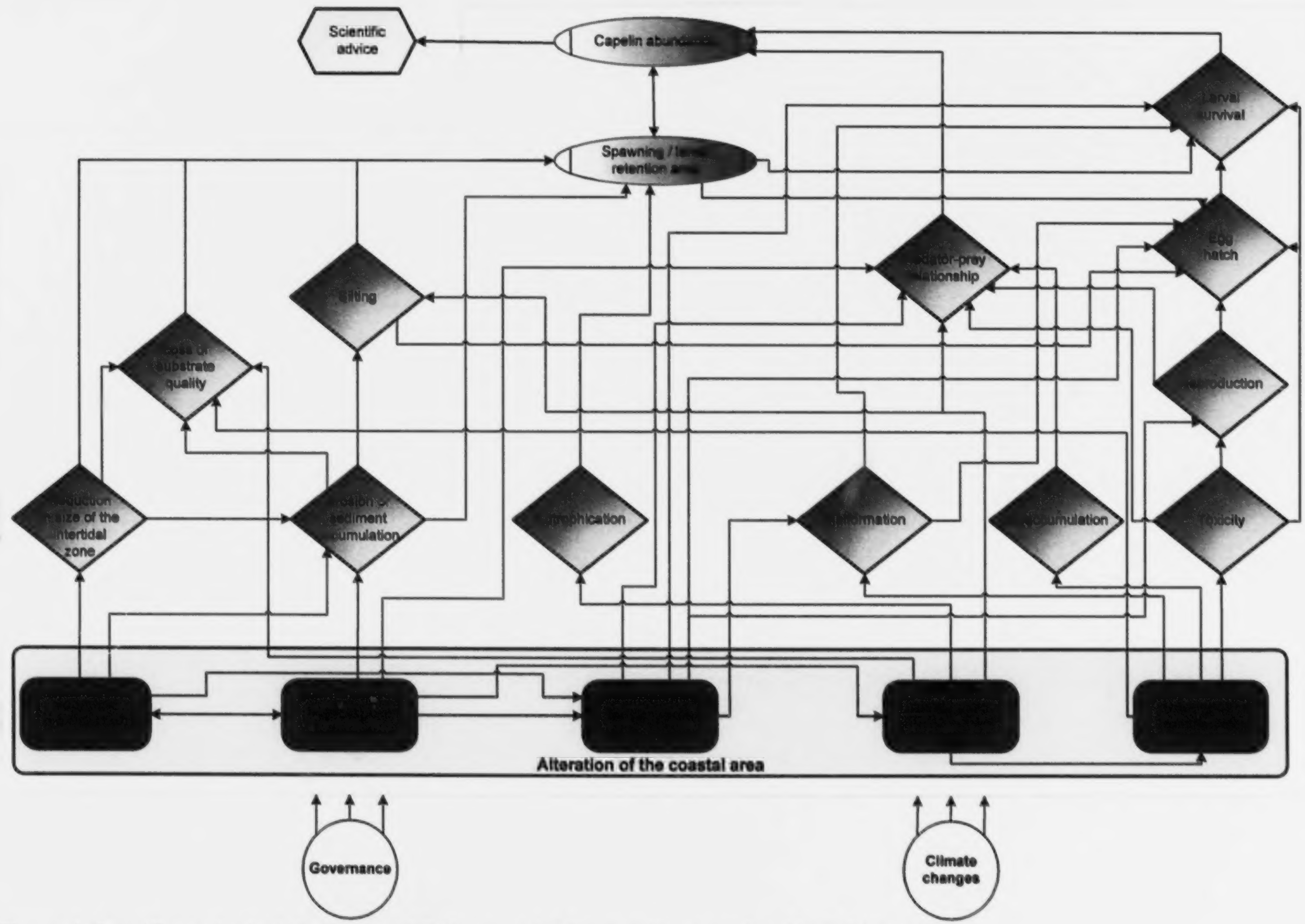

Figure 4. Specific ecological Pathways of Effects model for capelin spawning / larval retention area.

3.2.1.3 Stressor *modification of water temperature and/or salinity*: any activity that can modify water temperature or salinity has the potential to affect capelin conservation. The species' range is limited by these parameters: capelin inhabits waters that range from brackish to oceanic (Stergiou 1991) and its thermal preferences range from 1 to 14°C (Stergiou 1991). Since it does not produce an antifreeze protein, temperatures below -1.9°C are fatal (Mowbray 2002). Hence, one of the main factors limiting the range and migration of adult capelin would be temperature or changes in the range of plankton and prey, these latter changes also associated with water temperature (Stergiou 1991, Rose 2005). According to Jàkupsstovu and Reinert (2002) and Rose (2005), capelin appears to react quickly to changes in water temperature by modifying its range.

Furthermore, water temperature is one of the factors that most influences the metabolism and disease vulnerability of aquatic organisms (Bacon et al. 2005). Abiotic variables that act at critical moments in larval development can also be significant cohort regulators (Leggett et al. 1984). Higher water temperatures can reduce reproductive success by influencing egg-laying success, egg incubation, and larval hatch (Nakashima and Wheeler 2002). In the Gulf of St. Lawrence, the recent variations in water temperature appear to have significantly affected various aspects of the capelin's life cycle, notably its range, egg laying, and growth (Nakashima 1996, Grégoire 2004). However, the impact of these temperature variations on the species' natural mortality, production, and recruitment is as yet unknown (Grégoire 2004).

3.2.1.4 Stressor *modification in organic matter and/or nutrient input*: human activities can increase the quantity of organic matter and nutrients from the soil that are transported by water action (rain or snow melt). River water generally contains higher concentrations of nutritional substances than the upper layers of ocean water. Therefore, it can be a significant source of nutrients for estuary or inshore waters (Yeats 1988) and would be correlated with fish production in the Gulf (Sutcliffe 1973, Yeats 1988, MCI 2009a). The arrival of spring freshets carrying large quantities of organic matter and nutrients coincides with plankton bloom (Levasseur 1996). This synchronicity allows young capelin to feed in the spawning area.

If present in too large a quantity and depending on local environmental conditions (e.g., currents, topography) these inputs can lead to the eutrophication of an inshore habitat (DFO 2003, Dufour and Ouellet 2007). Organic matter, when suspended in the water column or settled on the bottom, can also disturb spawning / larval retention area in a number of direct (e.g., silting, turbidity) or indirect (e.g., eutrophication, influence on capelin prey) ways. For example, massive input can lead to malformations in developing embryos. According to Nakashima and Wheeler (2002), abnormal development tends to reduce hatch rate. In contrast, an activity that causes nutrients or organic matter, particularly those originating in watersheds, to be held back could also upset the sedimentary balance of the environment.

3.2.1.5 Stressor *introduction of contaminants*: multiple contaminants are introduced into the marine ecosystem by surface runoff, urban and industrial effluents, and from marine waters (accidental wastes) or from the atmosphere (in the form of gases or aerosols) (Dufour and Ouellet 2007). The presence of contaminants, in the particles suspended in the water column or stored in sediment, can lead to a reduction in the quality of spawning sites. This situation is reflected by a reduction in reproductive success and in the survival rate of eggs or

larvae, and hence contributes to reducing the abundance of populations (see Appendix 7). Also, a number of studies have shown that contaminants have direct harmful effects on several aspects of the life cycles of finfish (Dufour and Ouellet 2007). For instance, some contaminants are acutely toxic to finfish and can cause increased mortality in mature fish, thus reducing spawning stocks and consequently the number of eggs produced. Fish that are chronically exposed to contaminants can suffer from a general deterioration in health, which adversely impacts the quality and quantity of eggs laid and consequently the recruitment abundance. Some of the potential impacts associated with contaminants that can be mentioned are the tissular malformations caused by heavy metals (Mance 1987, Sorenson 1991) and the neurotoxic, embryotoxic, hepatotoxic, and androgenic effects induced in fish by tributylin (TBT) (Fent 1996, 2006).

3.2.2 Description and interpretation

This first specific ecological model illustrates the fact that each of the 12 main impacts identified is connected to at least one stressor, but also that they may be generated by more than one stressor. For instance, erosion or sediment accumulation can be provoked by a shoreline modification or by changes in the hydrological regime. It is important to point out that an impact can also generate another impact. In the preceding example, erosion or sediment accumulation is also induced by a reduction in size of the intertidal zone. Lastly, it appears that stressors are sometimes interconnected even if this particular characteristic differs from PoE theory. Because the models are being applied to a real situation, the adjustment was kept because it helps illustrate documented facts, such as a change in the hydrological regime that in turn leads to a change in the input of organic matter and nutrients.

To make it easier to describe the model, it is possible to consider one stressor at a time. Thus, after examining the effects specific to *shoreline modification* (Figure 5), it appears that the major potential impacts generated by this stressor would be a reduction in size of the intertidal zone and erosion or sediment accumulation. These impacts can have a direct effect on capelin spawning / larval retention area and consequently on capelin abundance. However, it is interesting to point out that these two impacts (reduction in size of the intertidal zone and erosion or sediment accumulation), through the secondary impacts they provoke, can also have indirect effects on the measurable endpoints. Indeed, they could both cause a loss of substrate quality. Erosion or sediment accumulation can also lead to silting which in turn can influence egg hatch rate and larval survival.

The specific pathway for modification of the hydrological regime shows that impacts on predator–prey relationships and on erosion or sediment accumulation would be the major effects to be anticipated. Secondary impacts could be loss of substrate quality and silting. In practical terms, the modification of the hydrological regime can also lead to habitat loss due to erosion or substrate modification.

In the pathway for modification of water temperature and salinity, potential impacts could be direct and involve predator–prey relationships and larval malformation and/or survival.

For the particular pathway of effects for modifications in organic matter and nutrient input, the diagram serves to show that malformations, silting, and disturbance of the predator–prey relationships would be the major potential impacts directly associated with this element. This pathway serves to show the fact that a massive input of organic matter and nutrient would modify the spawning area and substrate quality, and can even eventually destroy the area for years to come (MCI 2009a).

Finally, depending on the relationships presented in the specific pathway for the introduction of contaminants, the potential direct impacts that could be generated are malformations, bioaccumulation, and toxicity. Toxicity itself could provoke a disturbance in reproduction, egg hatch, and larval survival rates. Predator–prey relationships could also be affected.

It is important to point out that as a whole this specific ecological model provides a complete, albeit complex, view of a situation. Consequently, it is difficult to interpret all aspects of the model. Despite this inconvenience, it is advantageous to illustrate a problem with such precision, primarily as a means of illustrating the potential issues specific to a stressor in order to gain a greater understanding of these issues and to take them into consideration during future management and conservation actions. To consider other potential avenues of analysis or other more in-depth analyses for this first specific ecological model, additional information is presented in Appendix 8.

3.3 SPECIFIC ECOLOGICAL MODEL FOR ABUNDANCE

3.3.1 Presentation of the model and its main elements

The second specific ecological model serves to study the pathways for the measurable endpoint *capelin abundance*, which is intimately connected to the stressor *biomass removal*.

The model diagram presented in Figure 5 shows that only fisheries would effect a direct removal of capelin biomass. This human activity sector includes the commercial fishery; food, social, and ceremonial fishery (FSC); the recreational capelin fishery; and the biomass removed through bycatch in other fisheries. In the following sections, each of these elements is characterized and its connection to the potential impacts on the measurable endpoint shown: reduction in abundance or in spawner biomass, disturbance of the predator–prey relationship (fewer resources for predators, for instance), erosion that could induce a loss of substrate quality, and possible changes in the size of individuals caused by the selection of particular size categories by fisheries. Some potential modulating factors from anthropogenic or natural sources are also shown: life cycle, governance, and market. As with the preceding ecological model, scientific advice describes the measurable endpoint *capelin abundance*.

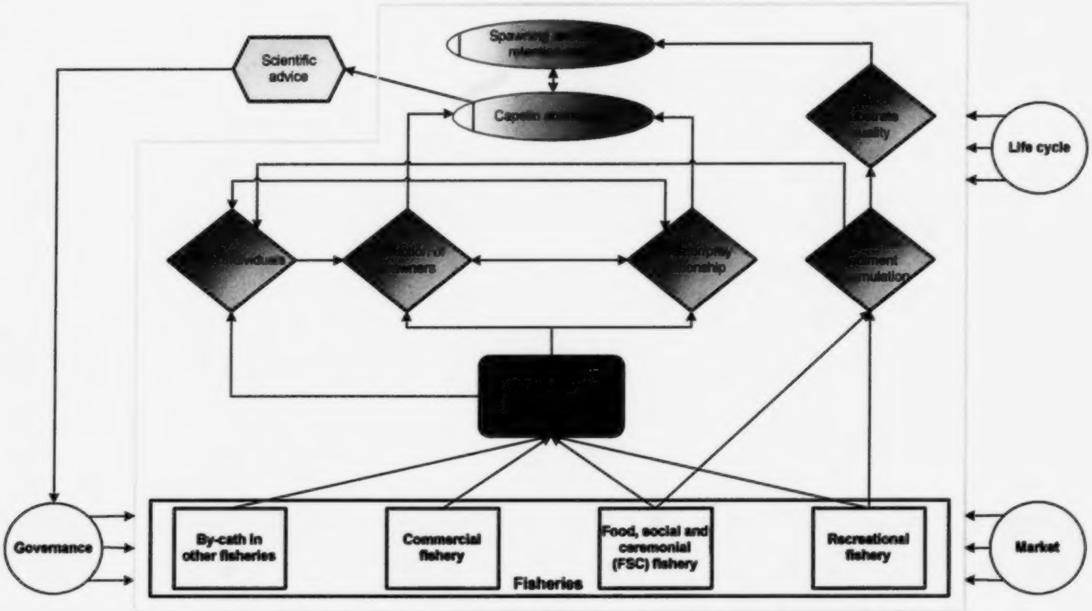

Figure 5. Specific ecological Pathways of Effects model for capelin abundance.

<u>3.3.1.1 Commercial fishery</u>: There is a commercial capelin fishery in the study area that contributes to the capelin biomass removal. The purse seine, trap net, and weir are the gear used for this fishery (Grégoire et al. 2008). Fishing seasons are generally short, from May to July depending on the region. The purse seine season takes place before spawning while the trap net and weir seasons occur the spawning period (DFO 2008b). The major capelin landings in the Estuary and Gulf of St. Lawrence are associated with the purse seine fishery off the west coast Newfoundland (North Atlantic Fisheries Organization [NAFO] Division 4R) (Grégoire 2004). On Québec's Lower North Shore, fishers primarily use trap nets while capelin in the St. Lawrence Estuary is fished mostly using weirs (NAFO Divisions 4S and 4T) (DFO 2008a). Purse seine and trap net fishing target mature females for their eggs (roe), which are exported and used as caviar (*masago*) (Dumont and Provost 2008).

Since 2005, a total allowable catch (TAC) of 11,200 t has been allocated to Division 4R (west coast of Newfoundland) and 1,800 t altogether for Divisions 4ST (Estuary and Gulf of St. Lawrence) (DFO 2008b). Fish meal production and the opening of a lucrative Japanese market for roe-bearing females in the late 1970s spurred the rapid development of the commercial fishery in the Gulf of St. Lawrence. From an annual average of nearly 700 t between 1960 and 1976, Gulf landings very quickly soared to nearly 10,000 t per year after 1978 (Grégoire 2004). Since 2006, landings have always exceeded 10,000 t (with a record 11,833 t in 2006) except in 2007, when landings totalled 7,900 t, probably due to reduced catches in the southernmost areas along the west coast of Newfoundland (DFO 2008b).

<u>3.3.1.2 Recreational fishery</u>: The recreational capelin fishery is practised on some beaches in the study area during the capelin spawning season (described in Section 2.2.2), which

generally lasts from four to six weeks. Dip nets, pails, and even bare hands are used to harvest capelin (Giroux et al. 2008). No assessment of the quantity of capelin harvested in this way has been conducted, but catches should be very minimal compared to commercial fishery catches (François Grégoire, DFO, pers. comm.). However, even without this activity, most males die (nearly 100%) after spawning and only a few females survive (DFO 2008b).

3.3.1.3 Food, social, and ceremonial (FSC) fishery: The FSC capelin fishery is a traditional activity and unique in its kind. It requires little organization and still persists to this day in the study area. This sub-activity was considered in the model although it is difficult to assess the quantities taken, as is also the case for the recreational fishery. This type of capelin fishing appears to harvest only a very small proportion of the biomass (François Grégoire, DFO, pers. comm.).

Every spring on the shores of the Estuary and Gulf of St. Lawrence, hundreds of people of all ages get together in the evening and wait for the capelin to "roll." From biological and social perspectives, this activity is a unique phenomenon (Dumont and Provost 2008). Traditionally, capelin was used to fertilize fields, as bait for fishing and food for sled dogs, to bait the traps used to catch fur-bearing animals, and to rear foxes, to make fish meal, or simply for human consumption (fresh or salted) (Grégoire 2004, Dumont and Provost 2008). Capelin has been part of the diet of the Aboriginals of Québec's North Shore for a very long time, and they are very familiar with its spawning habits (Giroux et al. 2008).

3.3.1.4 Bycatch in other fisheries: In the study area, it appears that capelin is a regular bycatch in the northern shrimp (*Pandalus borealis*) fishery. Capelin catches by shrimpers can be large, particularly in the spring (Grégoire 2004). According to data gathered via Fisheries and Oceans Canada's Observers Program, capelin bycatches by shrimpers decreased from 887 t in 1993 to a low of 113 t in 1996. Capelin catches have since fluctuated, with values ranging between 110 t (2007) and 536 t (2009) (DFO 2011). Most of these catches were made in the Sept-Îles shrimp fishery management area (Grégoire et al. 2008), except for 1993, 2002, and 2009, when the dominant area was the Esquiman region (DFO 2011). These catches are generally discarded (Grégoire and Hurtubise 1996). Although the volume is rather small, capelin bycatch can also occur in the herring fishery (Jangaard 1974; Statistical Services Unit, DFO, unpublished data).

3.3.2 Description and interpretation

This second specific ecological model is simpler in appearance than the first model, primarily because of the nature of the stressor *biomass removal*, which is less complex. In fact, in the case of capelin, this stressor appears to be generated by a single human activity: fishing. Consequently, there are fewer impacts and relationships connecting each of the elements, which makes interpreting the whole model easier. Also, and in contrast to the preceding model, it does not appear to be necessary to subdivide this stressor.

One of the main points to retain regarding this model is that each fishery activity involves direct removal of capelin biomass to some degree; consequently, each has a direct effect on species mortality, with its extent depending on the intensity of the fishing effort. However, according to

current estimates, the capelin mortality rate due to fishing is apparently only a small proportion of the total capelin mortality rate, including natural causes (predation [see Section 3.4] and other natural causes of death [e.g., illness, old age]).

The model also shows that recreational and FSC fishing can lead to erosion due to some particularities specific to these fishing operations. Indeed, they often involve the use of all-terrain vehicles (ATVs) directly on the beaches. The repeated passage of ATVs destroys the vegetation present there, thus accelerating the phenomenon of erosion and possibly leading to a loss of substrate quality. The loss of habitat suitable for capelin reproduction can lead to beaches being deserted by the species (Dumont and Provost 2008) and thus influence population abundance. Also, the ATVs passing along and disturbing the lower beach area would contribute to uncovering or even destroying eggs (Hans-Frédéric Ellefsen, DFO, pers. comm.).

The model also shows the relationships that exist between biomass removal and its potential direct impacts: reduction of spawners, disturbance of predator–prey relationships, and reduction in the size of individuals. According to Dufour and Ouellet (2007), fishing activities can strongly influence the structure and functioning of the ecosystem by modifying interspecies competition and predation relationships. For instance, any increase in capelin mortality through fishing could reduce the biomass available to predators. However, given current fishing levels, it seems unlikely that catches limit the availability of capelin (DFO 2008c). In contrast, any reduction in predator biomass as a result of fishing could reduce predation pressure on capelin and thus foster population growth (Worm and Myers 2003, Savenkoff et al. 2007a). Finally, although the impact of fishing on the size of individuals is difficult to establish for capelin, it has been proven for other species caught commercially that a drop in the mean length of individual fish in a stock occurs when the fishing effort is high (Trites et al. 2006).

The model also presents relationships existing between scientific advice, species abundance, and governance. For example, the management measures put in place by DFO (governance) seek to ensure the sustainable use of resources by taking into consideration, among others, the status of stocks as shown in the scientific advice. Also, scientific advice can itself increase the effect of the modulating factor on the human activity, and consequently on the stressor, by establishing a total allowable catch (TAC) that is too high for the species. At present, the TAC for capelin is low compared to population estimates (DFO 2008b, Grégoire et al. 2008). Since there is no abundance survey specifically for capelin, it is impossible to calculate the capelin stock's absolute abundance and thus assess the true mortality due to fishing (DFO 2008b).

Finally, the market is another modulating factor that can influence fishing effort. The current demand for capelin is growing, so the fishing industry is interested in increasing their harvest.

3.4 SPECIFIC ECOLOGICAL MODEL OF THE TROPHIC SYSTEM

3.4.1 Presentation of the model and its main elements

The third specific ecological model presents the trophic system associated with capelin (adults and large juveniles). It serves to identify and detail the relationships surrounding one of the impacts identified in the specific ecological model for capelin abundance—the impact of

predator–prey relationship. Based on Gulf ecosystem models (CEEDNA 2003; Savenkoff et al. 2004, 2007a, 2007b, 2009), the diagram describes the principal trophic interactions associated with capelin (principal predators, competitors, and prey). The need to create a model of this type is justified by (i) the key importance of capelin in the Gulf of St. Lawrence ecosystem and (ii) the variations in its abundance being primarily due to natural factors: the most important cause of mortality in capelin is predation (Grégoire et al. 2008).

Although the description of the predator–prey relationships associated with capelin is aligned with PoE model theory, the diagram in Figure 6 has nonetheless been adapted to suit the particularities of the model itself. The main natural stressors that influence the capelin's trophic system are (i) the availability of food resources (its main prey), (ii) the competition for these resources (its main competitors), and (iii) predation (its main predators). These stressors are described below; additional information concerning the impact of predator–prey relationships is provided in Appendix 7.

3.4.1.1 Principal capelin prey: There is little recently published information about capelin diet. Several studies have shown that this fish feeds primarily on zooplankton (e.g., copepods, euphausiids, amphipods) (Jangaard 1974, Vesin et al. 1981, Pitcher et al. 2002, Bundy 2004, D. Chabot, DFO, unpublished data). In 2003, stomach content analyses were conducted on capelin caught in the Estuary and northern Gulf (D. Chabot, DFO, unpublished data). The results served to make regional distinctions in the zooplanktonic prey ingested by capelin. Thus, euphausiids constituted 100% of the capelin diet in the Estuary, 63% in the northern Gulf (hyperiid amphipods and copepods: 33% and 4% respectively), and only 19% to the west of Newfoundland (hyperiid amphipods and copepods: 4% and 76% respectively). Moreover, the proportion of fish in the capelin diet appears low (< 4%) and is essentially accounted for by cannibalism (Savenkoff et al. 2004, 2009). It is also recognized that capelin feeding activity varies by season. For instance, capelin stops feeding entirely when spawning and gradually resume thereafter.

3.4.1.2. Principal capelin competitors: According to the ecosystem models produced for the northern (from 2003 to 2005) and the southern (from 1994 to 1996) parts of the Gulf of St. Lawrence by Savenkoff et al. (2007b, 2009), capelin is apparently the main fish predator of zooplankton. In addition to capelin, other important predators of zooplankton in the northern Gulf appear to be shrimp (especially the northern shrimp [*Pandalus borealis*]), pelagic fish (especially herring [*Clupea harengus*], mackerel [*Scomber scombrus*], sand lance [*Ammodytes* spp.]), and redfish (*Sebastes* spp.) (CDEENA 2003, Savenkoff et al. 2009). In the southern Gulf, the situation differs slightly and the principal predators for zooplankton appear to be pelagic fish (herring and mackerel), cod, American plaice (*Hippoglossoides platessoides*), and shrimp. Throughout the Gulf, zooplankton also exerts significant predation pressure on itself through cannibalism or predation of the smallest species (e.g. copepods) by large species (e.g., euphausiids and amphipods) (CDEENA 2003, Savenkoff et al. 2007a, 2007b, Marion et al. 2008).

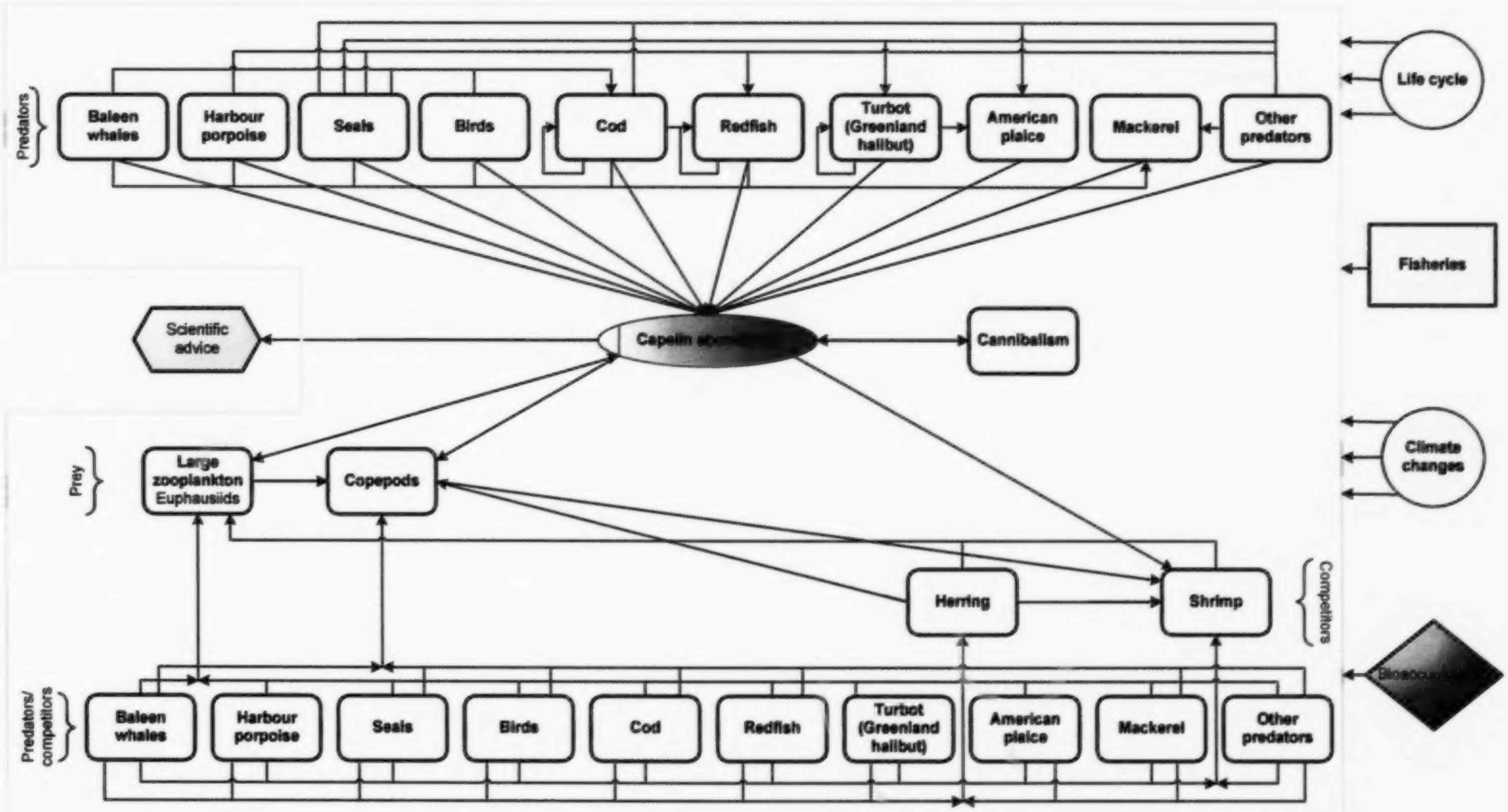

Figure 6. Specific Pathways of Effects model illustrating predator–prey relationships associated with capelin.

Hence, although capelin is one of the main predators of zooplankton in Gulf of St. Lawrence ecosystems, it competes with organisms at all trophic levels—whether higher up or lower down—for its principal food source. However, its main competitors are herring and shrimp (especially northern shrimp in the northern Gulf). Studies have shown that capelin populations appear to be highly affected in years when herring is present in great numbers in the Barents Sea (Hopkins and Nilssen 1991, Olsen et al. 2009). Two factors could explain these opposite trends: either predation of capelin larvae by herring or competition for food. The various competitors could influence the availability or accessibility of the capelin's food resource and thus have an impact on its abundance in the Gulf.

3.4.1.3 Principal capelin predators: With the exception of plankton, capelin was the main prey in the northern Gulf of St. Lawrence ecosystem from the mid 1990s to the mid 2000s, representing on average about 50% of all the material consumed in the ecosystem (Savenkoff et al. 2007a). Recent ecosystem models (for the period from 2003 to 2005) report that nearly 430,000 t of capelin were consumed annually by these main predators: cetaceans, harp seals (*Phoca groenlandica*), and Greenland halibut (*Reinhardtius hippoglossoides*). After capelin extended its range in the southern Gulf beginning in the mid 1990s (Grégoire et al. 2005), this species became the system's main prey (about 30% of all the material eaten), if plankton prey are excluded (Savenkoff et al. 2007b). Its main consumers, according to the ecosystem model for the 1994–1996 period, were harp seals, small piscivorous fish (especially herring), adult cod, grey seals (*Halichoerus grypus*), and cetaceans (especially minke whales [*Balaenoptera acutorostrata*] and harbour porpoises [*Phocoena phocoena*]) (Savenkoff et al. 2007b). Lastly, the impact of capelin fishing throughout the Gulf was very limited compared to that of predation.

3.4.2 Description and interpretation

The specific ecological model for the food chain (Figure 6) illustrates the relationships between organisms (prey, competitors, or predators) that have the potential to directly or indirectly influence variations in capelin abundance. It reveals that the main capelin predators in the Gulf of St. Lawrence ecosystem not only eat capelin but are also potential competitors for its food and influence each other (for instance, harp seals eat cod, cannibalism in cod) Moreover, changes in predator abundance (and hence in predation pressure) can lead to changes in the distribution of prey. Mowbray (2002) suggested that the use of deeper layers in the water column by Newfoundland capelin since 1991 was caused by a massive reduction in the numbers of their main predator, cod, rather than by an increase in pelagic fish populations in this region. Trophic interactions associated with capelin can be affected by many factors, including changes in (i) the life cycle and productivity of capelin and others species of the trophic system, (ii) environmental factors acting on capelin distribution, (iii) contamination and its trophic transfer (bioaccumulation) in the ecosystem, and (iv) the fisheries. These changes can influence capelin abundance and consequently the formulation of scientific advice regarding its assessment.

This type of model shows managers that an action directed at another species could affect capelin conservation because of the possible trophic relationship between the two species.

3.5 SPECIFIC SOCIO-ECONOMIC AND CULTURAL MODEL FOR SPAWNING / LARVAL RETENTION AREA

3.5.1 Presentation of the model and its main elements

The first specific socio-economic and cultural model serves to present in greater detail the potential relationships surrounding the goods and services provided by spawning / larval retention area and the eventual consequences that the alteration of such areas or the implementation of governance measures for such areas could have on the economy and on the various social and cultural values. According to the concept of goods and services produced by the ecosystem (MA 2005), spawning / larval retention area provides provisioning and/or cultural services to humans, thus supporting the economic cycle and the cultural heritage of those who use them.

The model diagram, presented in Figure 7, shows the two ecosystem services involved. The only human dependency that would be directly connected to the measurable endpoint involves recreation and tourism activities. Direct and indirect dependencies as well as the various consequences that arise from them are also shown. The following sub-sections (3.3.1.1 and 3.3.1.2) present the main information gathered concerning the ecosystem's goods and services pertaining to this model.

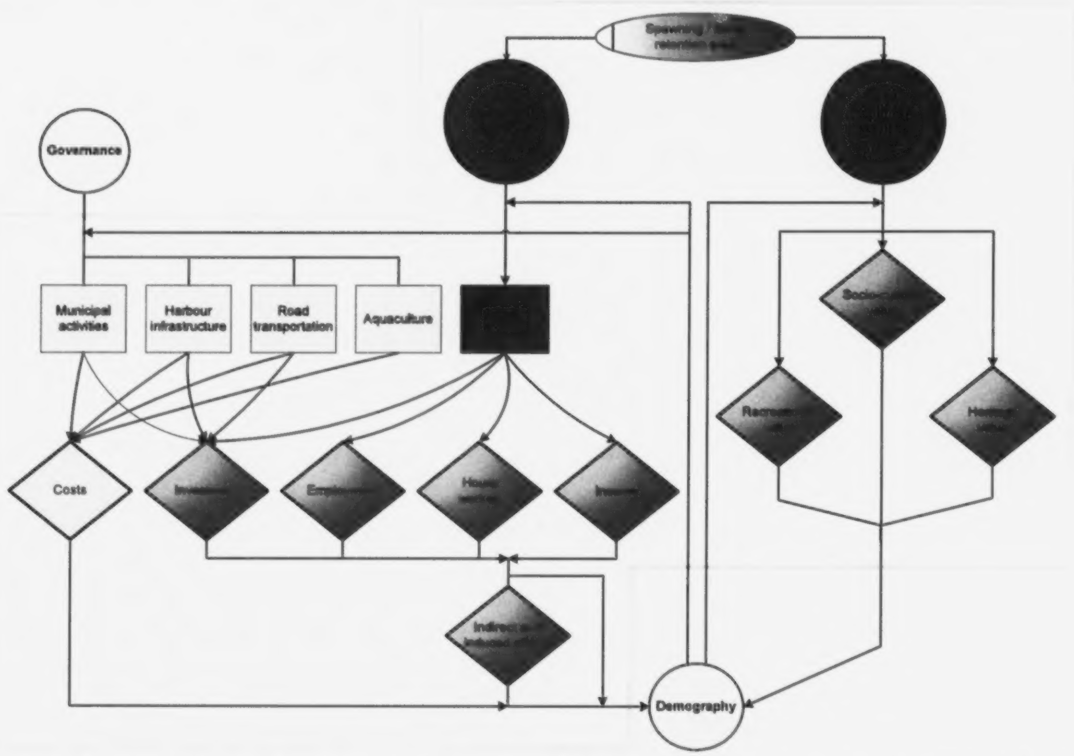

Figure 7. Specific socio-economic and cultural Pathways of Effects model connected to spawning / larval retention area.

3.5.1.1 Provisioning services: in Québec, capelin is not a species of commercial importance. In 2008, the value of capelin landings was $240,380 for about 25 fish harvesters, and some assistant fishers (Statistical Services Unit, DFO, unpublished data). These fish harvesters, located primarily on the North Shore, have annual landings of $30,000 on average, one third of which is derived from capelin. Although at present only three fish harvesters depend entirely on capelin (over 75% of their landings are capelin) and only four fish harvesters land more than $15,000 per year worth of capelin, the capelin fishery often enables certain fish harvesters and assistant fishers to make ends meet or to work enough hours to qualify for employment insurance. However, the demand for capelin fishing licences appears to have been growing over the last few years, spurred by falling catches in other pelagic fish fisheries. Also, three or four plants process capelin on the North Shore (Statistical Services Unit, DFO, unpublished data). Lastly, it is important to point out that the diet of commercially harvested groundfish is in part composed of capelin. Hence, the capelin population indirectly provides income to a number of groundfish harvesters and ensures the maintenance of some marine mammal populations, which are essential to the tourism industry in the region.

3.5.1.2 Cultural services: a number of rites, customs, activities, and traditions are connected to capelin, particularly for North Shore inhabitants, but also for people living in the Gaspé. Dumont and Provost (2008) report the stories told by older members of North Shore communities, demonstrating the importance this species may have for this generation. But even today, "...capelin is associated with beach fires and boozy evenings" (translated from Dumont and Provost 2008). The first reports of capelin in a North Shore text go back to 1850, although there are older texts from Newfoundland (Dumont and Provost 2008). Capelin has been used for a variety of purposes for several generations, particularly by people living on the North Shore, so it has a heritage value (Section 3.3.1.3). Childhood memories associated with capelin fishing are important since they give roots to the North Shore fishing identity. Capelin is often the first fish North Shore inhabitants harvest during their childhoods. The context surrounding this event is particularly memorable (an activity on the beach in the evening or at night) for young children (Dumont and Provost 2008). Consequently, capelin has a high socio-cultural value for the inhabitants of the North Shore.

3.5.2 Description and interpretation

This first specific socio-economic and cultural model illustrates the context of human dependencies on the resource and on the capelin beaches, and the possible repercussions of spawning / larval retention area governance methods on certain human activities. This socio-economic and cultural model therefore complements the first ecological model and is necessary for an overall profile of the situation surrounding the targeted measurable endpoint.

Of the model's principal points, it appears that a future change in the provisioning services could directly influence affected industries, in this case recreation and tourism activities. This, in turn, could have measurable consequences on the local economy by influencing employment, investment, hours worked, and income. These consequences may also have repercussions on other activity sectors, such as indirect and induced effects (e.g., a reduction in a household income may result in less spending in local businesses by that household).

Moderating factors, such as governance, can have direct or indirect consequences on specific industries by implementing specific management or conservation measures for spawning / larval retention area. If such measures were to be established, the affected industries could have to significantly modify their activities and operations, which could lead to additional costs or new investments. For instance, a conservation measure could affect municipal activities in several ways, either by modifying the infrastructure already in place (for example, waste snow management or urban development), by modifying existing municipal by-laws, or by establishing new infrastructures (construction and maintenance costs for shoreline protection structures).

The local demography, another modulating factor, is also included in the model. The services provided by the resource, whether or not they contribute to the wealth and diversity of the regional socio-economic and cultural profile, can influence the population to stay or leave the area depending on the situation. For instance, a region whose economic activities or social cohesion is weaker could see its population fall. This situation could, in turn, bring about a deterioration in economic activities or social cohesion. This retroactive loop is shown in the model diagram.

Finally, this model also considers cultural services provided by the resource and their consequences on the associated recreational, socio-cultural, and heritage values. Capelin beaches are important for people living in the study area, particularly the inhabitants of the North Shore and the Gaspé Peninsula (Section 3.3.1.2). Often, above-mentioned values underlie these uses and convey the attachment, respect, and, to some degree, spirituality associated with the resource by the communities. A modification in the spawning / larval retention area, and the indirect effects on capelin abundance, would ultimately modify these values. Unlike the consequences on provisioning goods and services, consequences on the values associated with cultural services are not as easy to quantify, which makes it difficult to determine their economic significance.

3.6 SPECIFIC SOCIO-ECONOMIC AND CULTURAL MODEL FOR ABUNDANCE

3.6.1 Presentation of the model and its main elements

The second specific socio-economic and cultural model (Figure 8) details the potential relationships between the goods and services provided by *capelin abundance* and the consequences that the loss or alteration of this measurable endpoint, or the establishment of governance measures, could have on the economy and on the associated social and cultural values.

This model shows that capelin abundance has a direct connection to several industries, in this case the processing of capelin and other species, the capelin fishery and fisheries for other species, and recreation and tourism activities. These industries sometimes interact with each other and are ultimately connected to each of the various potential economic consequences identified (investment, employment, income, hours worked, and indirect and induced effects), which adds to the model's visual complexity without making its interpretation significantly more arduous.

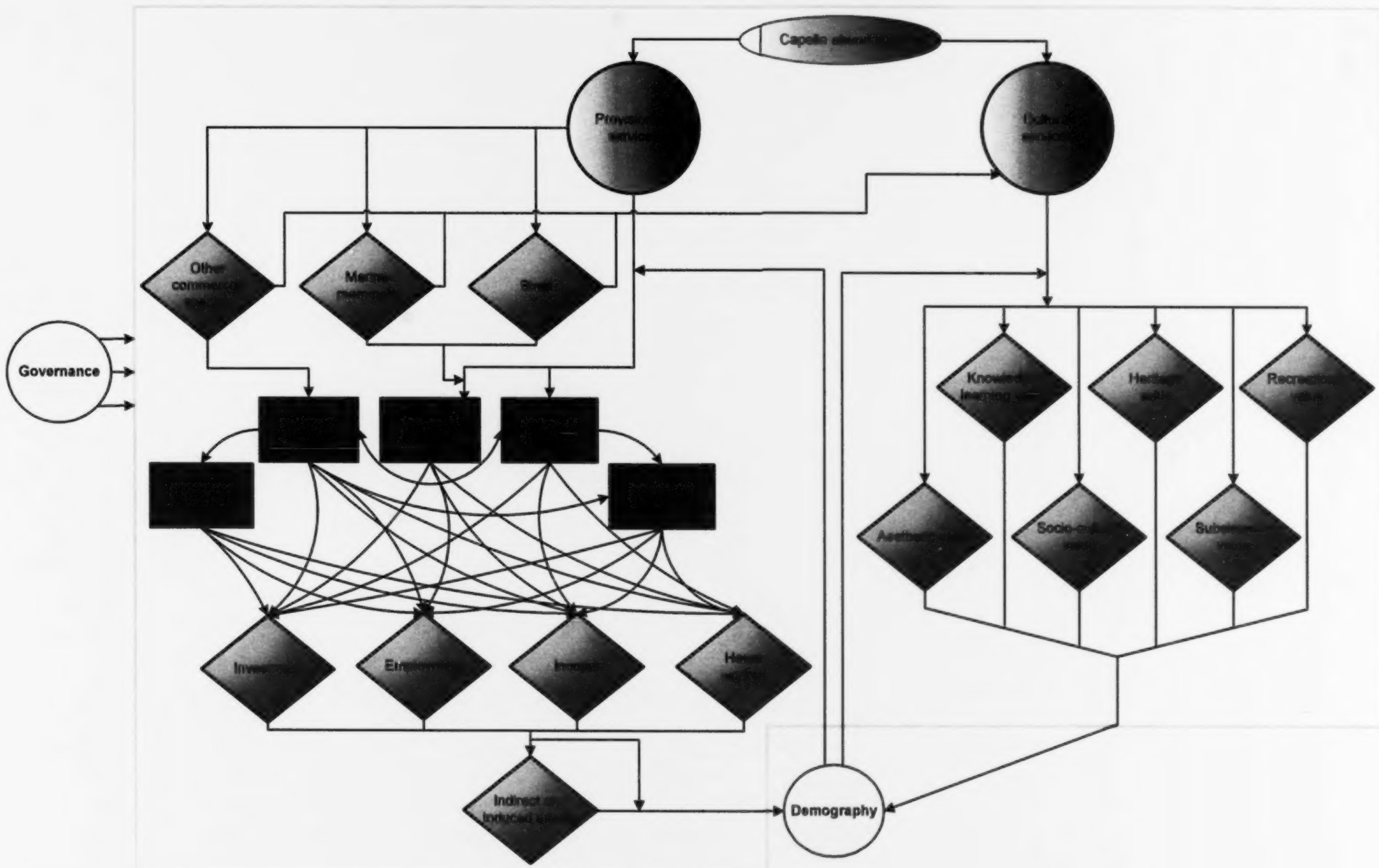

Figure 8. Specific socio-economic and cultural Pathways of Effects model associated with capelin abundance.

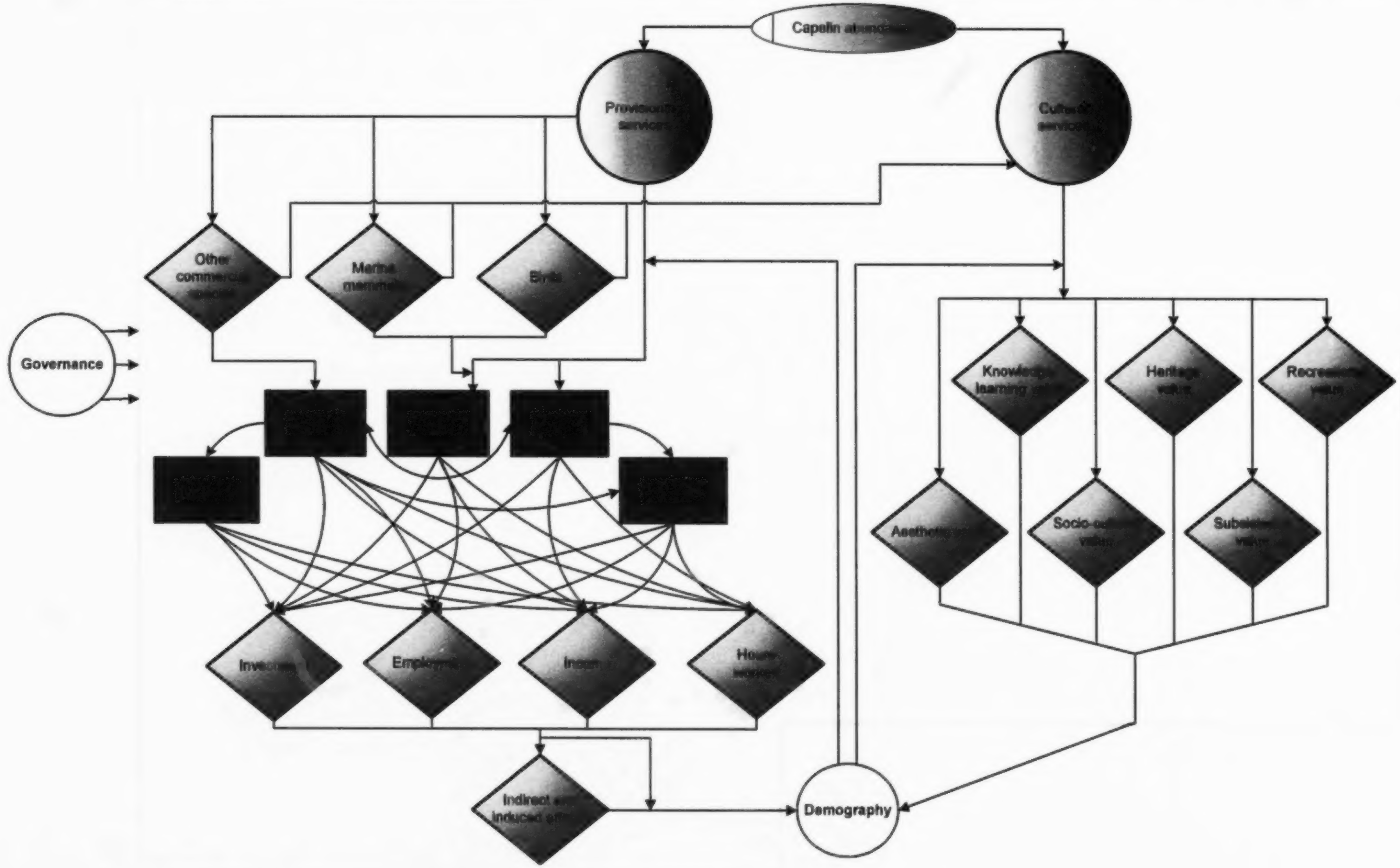

Figure 8. Specific socio-economic and cultural Pathways of Effects model associated with capelin abundance.

Capelin abundance provides provisioning and cultural services; the role these services play in supporting the local economy and the cultural heritage was presented in Sections 3.5.1.1 and 3.5.1.2. The model shows the potential consequences of modifications to these services on cultural and social values, various industries, and the presence of other commercial species, marine mammals, and birds, upon which some areas of human activity are dependent. The modulating factors that can affect the profile of the situation, governance, and demography are also shown.

3.6.2 Description and interpretation

As was the case for the first model, the information contained in this PoE can be analyzed from two perspectives. On the one hand, it reveals that capelin abundance provides services to society, which profits by and depends on them. On the other hand, it also implies that changes in the resource's level of abundance, whether or not induced by capelin conservation governance, are also felt by society. In more concrete terms, these services permit the creation of jobs and assure salaries for the people working in the industries that are directly affected. A certain economic turnover is associated with this resource, which translates into indirect and induced effects. In contrast, the management measures put in place can have an impact on the profitability of some businesses; examples include setting fishing quotas, raising the cost of bait, and modifying fishing periods. As in the case discussed in Section 3.5.2, a modification in the services provided by the ecosystem could, once again, have an impact on demography, which would in return have an impact on the industries, and so on.

It is interesting to point out that the principal governance measures that apply to abundance are those established by the government and that they seek to conserve the resource as recommended in the scientific advice documents via the TACs. These measures undoubtedly have an effect on the pathways as shown in Figure 8. So this governance can influence certain industries, regardless of whether they depend on capelin. Of these industries, it is interesting to see that the capelin fishery and recreation and tourism activities would be the only ones that are directly connected to the provisioning service. For instance, some tourism activities, like beach festivals and gatherings, depend directly on the numbers of capelin that spawn on the beach. Also, only recreation and tourism activities would be associated with capelin abundance via marine mammals and seabirds. As explained in Section 3.5.1.1, this is because capelin is a significant source of food for several marine mammal and seabird species. Marine mammals and seabirds are vital to some recreation and tourism activities (wildlife observation, for instance) and to significant cultural services in regions where capelin are found.

Processing activities generally take place in a plant and are intimately connected to fishing activities. A variation in capelin abundance can entail a modification in demand and in turn, a variation in this type of processing for capelin or substitute species. The quantity of capelin available can also have an impact on other fisheries. The influence can be positive, for instance, when it is used as a food source for other commercial species. Capelin may also be taken as bycatch (Section 3.3.1.4).

The model also presents the potential consequences specific to cultural services by showing the values affected (aesthetic, knowledge/learning, socio-cultural, heritage, subsistence, and

recreation). The relationships shown translate the information mentioned in Section 3.3.1.2. For instance, traditional cuisine and a general knowledge of the marine ecosystem (Dumont and Provost 2008) are two cultural components that would possibly be directly affected by capelin abundance. The aesthetic value associated notably with the presence of seabirds and marine mammals would serve to develop a tourism industry and improve living conditions for residents. Certain other events connected to the presence of capelin—like the Capelin Frolic, a major festival held from 1978 to 1992—can even potentially have large-scale cultural impacts.

The diagram can be used for several different kinds of analyses. It serves to precisely identify the advantages that an abundance of this resource can procure for society. It also serves to identify the probable effects a modification in capelin abundance, either through governance or otherwise, can have on all the associated economic, social, and cultural dependencies and consequences. Also, it can be combined with the second specific ecological model presented in Section 3.5 in order to draw a more comprehensive portrait of the PoE for the measurable endpoint *capelin abundance*. This ecological, economic, social, and cultural table provides a detailed view that is complementary to that provided by the holistic model.

4.0 DISCUSSION

Each of these models met the requirements of the PoE guidelines by showing different components of the issue and various levels of detail. They also served to show that this type of decision-making tool is pertinent and useful during identification and problem formulation, i.e., the first step of risk analysis. Indeed, while preparing the PoEs, the matter under study was identified and the needs revealed, thus making it possible to adequately pinpoint the issues connected to capelin conservation. As for the models and literature review, they contributed greatly to the issue's formulation. Phase I also served to gain a greater understanding of the mechanics of Pathways of Effects models and to use the tool in the context of a real situation. In addition, it helped to identify certain limitations to the model preparation process and to make recommendations on how to improve the results.

Of the identified limitations, the first is that the models' effectiveness depends greatly on the quality and quantity of the information gathered. This is why it is recommended that the necessary resources be dedicated to this step of the methodology. Nevertheless, it is possible that some information gaps will remain. However, preparing the PoE serves to identify them, which can in turn guide the acquisition of future knowledge. With this in mind, it would be important to close the knowledge gaps concerning capelin abundance and life cycle, the environmental factors influencing its annual migration patterns, and its spawning and larval retention areas (number, location and size of spawning grounds) (Grégoire et al. 2008). With regard to this last point, work is currently under way to determine the parameters of a good capelin spawning beach in the Gulf of St. Lawrence (François Grégoire, DFO, pers. comm.). As much as possible, additional information concerning human activities, stressors, and impacts should be collected to fully validate the pertinence of all the cause-and-effect relationships presented in the different models. It must be emphasized that the quality and quantity of data, and consequently the results, are influenced by the various choices made during the project (for instance, choice of study area, choice of species, and desired degree of detail).

Secondly, it is important to mention that a PoE's representation is the outcome of synthesizing, processing, and interpreting the information. Some information has been extrapolated, while other information has been adapted or rejected. In addition, although PoEs are based on scientific literature, part of the process nevertheless depends on the designers' judgment and is thus arbitrary. In the end, regardless of the matter undergoing risk analysis, the goal is to represent as faithfully as possible the entire targeted issue. However, the models produced must be considered flexible: they can be reworked, improved, and presented differently depending on the situation and thedata or knowledge acquisition. This is why there is no single model to represent a given issue.

The role of PoEs is to represent, synthesize, and communicate information, and they should serve to guide stakeholders, even from different horizons, when making decisions. PoEs are not designed to provide quantitative information that would serve to set a value for the different relationships, but they can nevertheless provide an illustration of the cumulative effects (for instance, the number of relationships surrounding a given element of the PoE). The need to quantify the information provided by the models will guide the next steps of the risk analysis process, in particular the risk assessment. This future step will notably quantify the risk associated with the various interactions between elements of the PoE and then use them concretely when the time comes to manage the risk. For example, pricing the relationships between the industry and the resource—including their economic, social, and cultural consequences—will provide a better guide to managers for economic purposes. The whole process will provide the basis for interacting and communicating with community stakeholders.

5.0 CONCLUSION

The first phase of this pilot project was conducted in the context of capelin conservation in the Estuary and Gulf of St. Lawrence and led to the production of six Pathways of Effects models. The PoEs developed as part of a risk analysis proces together take into account the ecological, socio-economic, community, and cultural aspects surrounding capelin conservation. In practical terms, the models provide the information needed to illustrate the issue comprehensively and to show the potential threats posed by human activities to spawning / larval retention area and to capelin abundance. In a yet broader perspective, PoEs are a highly effective communication and decision-making support tool, notably because they provide a solid foundation for risk analysis by identifying the issue adequately and by formulating the problem precisely. For this reason, the models produced during Phase I will guide the next steps in the risk analysis process undertaken by this pilot project—assessment (Phase II) and risk management.

In summary, production of the holistic model served to identify the anthropogenic components that can affect capelin conservation by providing a general view of the issue. Starting from this model, three specific ecological models were produced: the specific ecological Pathways of Effects model for spawning / larval retention area, the ecological Pathways of Effects model for capelin abundance, and the specific food chain Pathways of Effects model for predator–prey relationships. The first model describes the relationships between the potential stressors generated by the alteration of the coastal area and their impacts on the spawning / larval retention area. The second model highlights the relationships that exist between the various fishing activities, biomass removal, and impacts that can affect capelin abundance. As for the third

model, it served to gain an understanding of the interactions between capelin prey, competitors, and predators and capelin abundance. This model also made it possible to visualize the complexity of the trophic system and to imagine the effects that one or more human activities could produce in this balance. Two specific socio-economic and cultural models connected to spawning / larval retention area and capelin abundance made it possible to identify the industries whose economic viability depends on the species, estimate the importance of capelin to the well being of communities, and identify the industries that could be affected by the implementation of governance measures or by alteration of the resource.

The models produced during Phase I can evolve over time if necessary because of their simple and flexible structure. They can be improved or modified whenever pertinent scientific information becomes available or is updated; but especially, they can be adapted to suit the needs of the stakeholders involved and the community.

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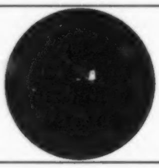
8.0 APPENDICES

Appendix 1. Composition of the DFO working group that collaborated in phase I of the pilot project.

Participant	Branch and Sector	Region
Arseneau, Cédric	Fisheries and Aquaculture	Québec
Bilodeau, Francis	Policy and Economics	Québec
Cabana, Anne-Marie	Oceans, Habitats and Species at Risk	Québec
DeMaio-Sukic, Alejandro	Policy and Economics	Central administration
Dufour, Réjean	Science	Québec
Ellefsen, Hans-Frédéric	North Shore Sector	Québec
Giangioppi, Martine	Ocean Policy and Planning	Central administration
Grégoire, François	Science	Québec
Hazel, François	Oceans, Habitats and Species at Risk	Québec
Magassouba, Ali	Policy and Economics	Québec
Massicotte, Éric	Policy and Economics	Québec
Nellis, Pierre	Oceans, Habitats and Species at Risk	Québec
Perreault, Louise	Oceans, Habitats and Species at Risk	Québec
Savenkoff, Claude	Science	Québec
Tremblay, Gilles H.	Oceans, Habitats and Species at Risk	Québec

Appendix 2. Description of the various terms and symbols used in the Pathways of Effects models.

Only the categories and elements retained to establish the Pathways of Effects models for capelin conservation are presented here.

PoE element category	Definitions / *list of PoE elements retained for capelin*
	(Non-measurable) component or ecological function that is to be protected. • *Capelin conservation*
	Measurable ecological component linked to the endpoint that is to be protected. Since it is measurable, this component establishes the relationship between the endpoint (in this case, capelin conservation) and the management objectives determined by managers. • *Quantity and quality of capelin spawning / larval retention habitat* • *Capelin abundance*
	Free benefits that human populations draw from aquatic ecosystems. • *Provisioning services* • *Cultural services*
	Physical, biological, or chemical factors engendered by human activity that generate impacts (see definition) likely to affect the endpoint and measurable endpoints. • *Biomass removal* • *Modification of water temperature and/or salinity*[*] • *Modification of hydrological regime*[*] • *Shoreline modification*[*] • *Modification in organic matter or nutrient input*[*] • *Introduction of contaminants*[*]
	All human activities and actions whose accomplishment depends or may be directly or indirectly affected by a modification in the state of the endpoints or the goods and services associated with the aquatic ecosystem, or by the management measures put into place to protect the endpoint. • *Hydroelectric power generation and water management* • *Municipal activities* • *Recreation and tourism activities* • *Heavy industries* • *Maritime transport* • *Road transport* • *Oil and gas* • *Fisheries* • *Forestry* • *Agriculture* • *Aquaculture*

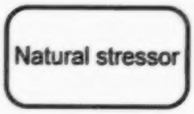
[*] These stressors are part of the "Alteration of the coastal area" category.

All human activities and actions that would be likely to affect the endpoint and measurable endpoints by inducing stressors. The human activities are elements to which management measures can apply.

- *Hydroelectric power generation and water management*
- *Municipal activities*
- *Recreation and tourism activities*
- *Heavy industries*
- *Maritime transport*
- *Road transportation*
- *Oil and gas*
- *Forestry*
- *Agriculture*
- *Aquaculture*
- *Fisheries*
- *Commercial fishery*
- *Recreational fishery*
- *Food, social and ceremonial fishery*
- *Bycatches in other fisheries*

All the effects induced by stressors on the biological, physical, geological, or chemical conditions of an environment. The effects in turn engender a measurable change in the conditions of the endpoint and measurable endpoints.

- *Reduction in size of the intertidal zone*
- *Erosion or sediment accumulation*
- *Eutrophication*
- *Malformation*
- *Bioaccumulation*
- *Toxicity*
- *Predator–prey relations*
- *Reproduction*
- *Egg hatch success*
- *Larvae survival*
- *Reduction in the number of spawners*
- *Size of individuals*
- *Loss of substrate quality*
- *Silting*
- *Cannibalism*



Species that have a significant nutritional connection (trophic interaction; i.e., prey, predators, and/or competitors) to the capelin and are thus able to affect its abundance.

- *Baleen whales*
- *Harbour porpoises*
- *Seals*
- *Birds*
- *Cod*
- *Large zooplankton – Euphausiids*
- *Copepods*
- *Redfish*
- *Turbot (Greenland halibut)*
- *American plaice*
- *Mackerel*
- *Herring*
- *Shrimp*
- *Other predators*

All conditions of a cultural, societal, or economic nature that influence human activities and consequently would be likely to indirectly affect the endpoint and measurable endpoints.

- *Market*
- *Governance*
- *Climate changes*
- *Demography*

All conditions of a biological, environmental, or ecological nature specific to the species or the ecosystem inhabited by the species and that are likely to indirectly affect the endpoint or measurable endpoints.

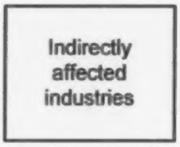
- *Life cycle*

All of the economic, social, and cultural elements that can be directly or indirectly affected not only by modifications in the endpoint and measurable endpoints, but also by the implementation of management measures put in place to protect the endpoint and measurable endpoints.

- *Birds*
- *Marine mammals*
- *Other commercial species*
- *Investment*
- *Employment*
- *Income*
- *Hours worked*
- *Indirect and induced effects*
- *Aesthetic value*
- *Socio-cultural value*
- *Subsistence value*
- *Knowledge/learning value*
- *Heritage value*
- *Recreational value*

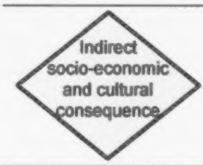
All activities of an economic nature that can be directly affected by modifications in the state of the endpoint and the measurable endpoints.

- *Capelin fishery*
- *Recreation and tourism activities*
- *Fisheries – other species*
- *Capelin processing*
- *Processing – other species*



All activities of an economic nature that can be indirectly affected by the management measures put in place to protect the endpoint and the measurable endpoints.

- *Municipal activities*
- *Road transport*
- *Harbour infrastructure*
- *Aquaculture*



All of the economic, social, and cultural elements that can be affected by the management measures put into place to protect the endpoint and the measurable endpoints.

- *Costs*

Reports dealing with the status of different marine organisms, stocks, or populations with issues connected to ecosystems, the environment, and species at risk, and with the evaluation of policy and management options. These reports are based on peer-reviewed scientific knowledge and results and are a reliable foundation for decision-making and management processes. They permit informed decision-making and the adoption of effective policies and strategies for achieving resource conservation objectives.

Appendix 3. Glossary for the holistic model.

The following definitions are adapted to the needs of the document.

Endpoint

Capelin conservation: Consists of preserving the integrity of capelin populations, subpopulations or stocks. The conservation objective selected for this project is described in Section 2.2.1.

Measurable endpoint

Quantity and quality of capelin spawning / larval retention habitat (spawning / larval retention area): Quality of biophysical properties, number, and size of areas used by capelin for its reproduction activities (spawning ground) and early life stages (larval retention or nursery ground). It is important to point out that for the purposes of this project and given the available data, this measurable endpoint excludes the deepwater spawning component—a little known phenomenon—and instead focusses on the inshore spawning area.

Capelin abundance: Total number of individuals or number of individuals per unit of space (surface or volume) constituting a capelin population, subpopulation, or stock in a given region.

Aquatic ecosystem goods and services

Provisioning services: Corresponds to the goods and services provided by the ecosystem (water, food, wood and other natural fibres, natural pharmaceutical products, etc). These goods and services are accounted for on the market and are thus easily quantifiable.

> *Decomposition*: Biological process involving the breakdown of a plant or animal organism.
>
> *Forage species*: Species situated lower on the aquatic food chain that are significant food sources for at least a few predators and that experience high mortality through predation.
>
> *Food source for marine mammals*: Potential prey for various marine mammal species and naturally present in their environment.
>
> *Aquatic resource harvest*: Exploitation of animal and plant resources in the natural aquatic environment (refers particularly to commercial fish stocks and populations) through commercial, sport, or subsistence activities.

Cultural services: Corresponds to non-tangible benefits that ecosystems provide through spiritual enrichment, recreational and cultural pleasures, experience, and aesthetic values as well as the pedagogical interest nature offers and which is useful to social relations and human learning. Cultural services are hard to quantify since they exist outside the market sphere.

> *Outdoor recreation*: Recreational activities practiced outdoors.
>
> *Aesthetics*: Refers to the perceptions and feelings that the natural environment provides.
>
> *Culture*: All the knowledge, practices, and usages connected to the natural environment that are shared and socially transmitted within a given group.

Spirituality: Actions (e.g., initiation, ritual, personal development) associated with the search for meaning, hope, and liberation that a natural environment can provide.

Stressors

Alteration of the coastal area: Stressor category that groups stressors that may induce changes in the biological, chemical, physical, or geological conditions of a coastal environment as a result of human activities or stressors of human origin.

Biomass removal: Capture of part of the total biomass of a stock or population (animal or plant) in its natural environment.

Human activities and socio-economic and cultural dependencies

Hydroelectric power generation and water management: **Hydroelectric power generation** relates to the conversion of the hydraulic energy generated by moving water (e.g., watercourses, waterfalls, waves, marine currents) to produce electricity. **Water management** concerns the regulation or artificial storage of a watercourse or water body by means of man-made infrastructure (e.g., hydroelectric dams, retaining dams, dikes) so the water can be reused for a variety of purposes (e.g. irrigation, industry, hydroelectricity, fish farming, potab!e water supply).

Municipal activities: Activities administered by municipalities, RCMs, and Aboriginal communities that can affect certain processes or elements of the natural environment. This activity sector is divided into two subcategories: the civil engineering and road network sector and the residential sector. The **civil engineering and road network sector** concerns activities connected to the development and management of a public area (e.g., deforestation, drainage, watercourse deviation), the construction and maintenance of public infrastructure (e.g., road system, waterworks, sewers), and public hygiene (e.g., wastewater and waste snow management, human waste management). The **residential activity sector** concerns activities connected to the development, management, construction, and maintenance of private land and infrastructure (e.g., shoreline modification, stabilization structures, iand drainage, presence or absence of vegetation, and septic tanks).

Recreation and tourism activities: All the activities connected to the leisure and tourism sectors (e.g., hiking and nature outings, including the use of motorized vehicles, pleasure crafting, marine mammal observations). The definition also encompasses the facilities required for these activities (e.g., hotels, marinas, hiking trails, trails for motorized sports), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., armouring, clearing), and the waste or other effects generated by these activities (e.g., introduction of exotic species into the environment, trampling, anti-fouling paint).

Heavy industries: The economic sectors connected with the production and processing of raw material (e.g., mines, metallurgy, chemistry, paper mills). The definition also encompasses industrial facilities (e.g., plants, foundries, refineries), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., deforestation, fill work), and the waste or other effects generated by these activities (e.g., atmospheric emissions, wastewater, accidental spills).

Maritime transport: The transportation of merchandise or people by ship. The definition also encompasses maritime facilities (e.g., ports, wharves, navigational locks, breakwaters), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., dredging, reinforcing), and the waste or other effects generated by these activities (e.g., introduction of exotic species into the environment, atmospheric emissions, ballast water, grey water, accidental spills, anti-fouling paint).

Aquaculture: All animal or plant production activities taking place in natural or artificial aquatic environments. The definition also encompasses aquaculture facilities (e.g., tanks and raceways, collectors, cages), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., water intake, armouring, watercourse deviation), and the waste or other effects generated by these activities (e.g., escape of exotic species into the environment; spread of disease; use of nutrients, antibiotics, and disinfectants).

Road transport: Land transportation of merchandise and people by road. The definition also encompasses road infrastructure (e.g., road system, bridges, and culverts), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., deforestation, drainage, earthwork), and the waste or other effects generated by these activities (e.g., dust and aerosol production, noise, modification of the local climate, habitat fragmentation).

Oil and gas: All the activities connected to the exploration (e.g., seismic surveys) and extraction (e.g., drilling) of oil and gas resources in the marine environment. The definition also encompasses infrastructure (e.g., drilling platforms, pipelines), the activities associated with the development, construction and maintenance of this infrastructure (e.g., pile driving, blasting), and the waste or other effects generated by these activities (e.g., drilling waste, atmospheric emissions, accidental spills, light pollution).

Fisheries: All activities involving the capture of aquatic animals in their natural environment, whether as part of a targeted fishery (commercial, recreational, or subsistence fisheries) or otherwise (bycatch). The definition also encompasses primary and further processing activities where the organisms are prepared for market distribution.

Forestry: All activities connected to forestry. The definition also encompasses infrastructure (e.g., logging roads, culverts, fords), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., clearing, brush cutting, drainage, fill work), and the waste or other effects generated by these activities (e.g., changes in the structure of ecosystems, soil compaction, habitat fragmentation).

Agriculture: All activities connected with the development of a natural environment for the production of crops or rearing of animals to meet the needs of human societies. The definition also encompasses infrastructure (e.g., irrigation systems, silos), the activities associated with the development, construction, and maintenance of this infrastructure (e.g., deforestation, drainage, fill work), and the waste or other effects generated by these activities (e.g., spreading and spraying of fertilizers or pesticides, use of hormones in animal husbandry).

Appendix 4. Glossary for the specific ecological models.

The following definitions are adapted to the needs of the document.

Impact

Reduction in size of the intertidal zone: Reduction in the extent of the foreshore (or tidal fall zone).

Loss of substrate quality: Change in the characteristics (e.g., size of sediment particles, concentration of dissolved oxygen, organic matter, contaminants) in the seabed or foreshore sediment.

Erosion or sediment accumulation: Process involving the breakdown (erosion) or build-up (accumulation) of material caused by factors of natural (e.g., waves, wind) or human (e.g., deforestation, construction) origin and leading to changes in the profile of the terrain.

Silting: Obstruction resulting from a modification in the input of sediment, organic matter, or nutrients.

Eutrophication: Modification and degradation of an aquatic environment generally explained by an excessive input of nutritional substances that leads to an increase in the production of algae and aquatic plants and thus, to premature senescence of the environment.

Malformation: Congenital morphological alteration of a tissue or organ following an abnormal development of the embryo caused by exposure to a contaminant present in the environment.

Bioaccumulation: The capacity of organisms to absorb, concentrate, and accumulate certain chemical substances in concentrations superior to those measured in the environment.

Predator–prey relationship: The disturbance of trophic relationships that connect different species where those in lower trophic levels are likely to be caught and eaten (prey) by others belonging to higher trophic levels (predators).

Toxicity: The capacity of a substance to provoke adverse and harmful effects in an organism.

Reproduction: Any disturbance affecting one or more stages in the process by which a species perpetuates itself by engendering new individuals.

Egg hatch: Disturbance of the hatching process when the animal leaves its protective envelop (egg).

Larvae survival: Modification in the survival rate of larvae or in the number of larvae (first developmental stage of an organism after hatching) that reach a later stage of maturity.

Size of individuals: Modification in the dimensions of an organism induced by a disturbance of some kind.

Reduction of spawners: Reduction of the stock or population composed of individuals that have reached sexual maturity and ensure the survival of the species.

Cannibalism: Behaviour that consists of eating another individual of the same species.

Stressor (that can cause alteration of the coastal area)

Shoreline modification: Modification or alteration of the original conditions of shoreline or riparian area—the transition area between a natural water body and the vegetation in the dry area—in response to human activities or stressors of human origin (e.g., disappearance of vegetation, armouring, fill work, trampling).

Modification of hydrological regime: Modification or alteration of the original conditions of the water flow (e.g., run-off, infiltration, evaporation) in response to human activities or stressors of human origin (e.g., construction of dams, bridges, watercourse deviations, deforestation).

Modification of water temperature and/or salinity: Modification of the original conditions of the water's temperature and salinity in response to human activities or stressors of human origin (e.g., deforestation, dam construction, watercourse deviations).

Modification in organic matter or nutrient input: Modification of the original conditions of the input of organic matter (composed of dissolved or particulate carbons of plant or animal origin) and nutrients (organic or mineral substances that can be directly assimilated by the organism) in response to human activities or stressors of human origin (e.g., wastewater emissions, ballast water, deforestation, spreading).

Introduction of contaminants: The input of any foreign biological or chemical agent or any other agent in abnormal quantities (unnatural quantities) into the environment as a result of human activities or stressors of human origin (e.g., atmospheric emissions, use of anti-fouling paint, accidental spills) that can compromise the integrity of the environment or the organisms present there.

Human and natural modulating factor

Market: The market concept can have a number of definitions for the purposes of this document. It can refer to a market specific to a region (e.g., Japanese market, Canadian market) or a market specific to a species or product (e.g., feed for aquaculture, capelin roe, bait) or quite simply the general play of supply and demand.

Governance: Joint actions by stakeholders from different public, private, and/or civic sectors and their participation in the process of overseeing, monitoring, and guiding various sectors of economic activity (e.g., fisheries, forestry, energy production) to ensure the formulation of wise policy decisions. In practical terms, the governance process can include the adoption of legislation and management measures and strategies. Any modification in the governance process can have repercussions on the behaviour of economic factors (e.g., increase or decrease in demand, jobs, production).

Climate change: Modifications in the climate directly or indirectly attributed to a human activity that alters the composition of the world's atmosphere in addition to the natural variability of the climate observed over comparable periods of time (MA 2005). Climate changes of anthropogenic origin are particularly attributable to greenhouse gas emissions (e.g., use of fossil fuels, deforestation, methane waste produced by agricultural activities).

Demography: Statistical and quantitative description of a human population (e.g., number, age structure, sex, birth rate, emigration rate) and its evolution in time and space as a function of the community's social, cultural, economic, and biological characteristics.

Life cycle: An organism's entire development period, including each stage of maturity and the steps that characterize these stages (e.g., growth, reproduction)

Human activity

Bycatch in other fisheries: Accidental captures of untargeted species or individuals (e.g., for reasons of size, maturity) by a given fishing effort.

Commercial fishery: Any fishing activity registered with the Department of Fisheries and Oceans and that is conducted using the fishing gear authorized by a commercial fishing licence.

Food, social, and ceremonial fishery (FSC): Fishing done by Aboriginal groups for food, social, or ceremonial purposes.

Recreational fishery: Fishing that is not considered commercial.

Appendix 5. Glossary for the specific socio-economic and cultural models.

The following definitions are adapted to the needs of the document.

Direct socio-economic and cultural consequences
Birds: All seabird species (e.g., Atlantic puffin, Arctic tern, black-legged kittiwake) that have trophic relationships with capelin and that are essential to cultural services or support activities of an economic nature (recreation and tourism activities).

Marine mammals: All marine mammal species (e.g., harbour porpoise, minke whale, harp seal) that have trophic relationships with capelin and that are essential to cultural services or support activities of an economic nature (recreation and tourism activities).

Other commercial species: All commercially harvested fish, crustacean, and mollusc species (e.g., cod, redfish, halibut, shrimp) that have trophic relationships with capelin, the resource considered in this effort. These species are essential to cultural services or support activities of an economic nature (e.g., fisheries, processing activities, recreation and tourism activities).

Investment: Some of the money invested or used to strengthen the potential of an enterprise or a sector of activity.

Employment: Number of jobs that depend on a given sector of activity (e.g., fishing, tourism) or a particular industry (e.g., fish processing plant, whale-watching enterprise).

Income: Pecuniary amounts collected by an individual (e.g., salary, inheritance), community (e.g., social contributions, membership fees, donations), or an enterprise (e.g., sales, subsidies).

Hours worked: Number of hours worked in a given sector of activity (e.g., fishing, tourism) or a particular industry (e.g., fish processing plant, whale-watching enterprise).

Indirect and induced effects: **Indirect effects** correspond to the socio-economic changes (e.g., variations in production, employment rates, income, investment) arising from intermediate consumption; in other words, the effects felt by the sectors of activity and enterprises that provide goods and services (inputs) (e.g., subcontractors, suppliers, cleaning service enterprises) to first line activities or enterprises. **Induced effects** correspond to the socio-economic changes (e.g., variations in production, employment rates, income, investment) generated by the expenditures and investments of salaried workers in the regional economy (e.g., purchase of goods and services, housing investments).

Aesthetic value: Value accorded to the ecosystem because of its beauty and other aesthetic criteria (e.g., landscape, animal or plant species).

Socio-cultural value: Value accorded to the ecosystem because of the spiritual, religious, or traditional uses it supports (e.g., Saint-Jean bonfires on the beach, place of worship).

Subsistence value: Value accorded to the ecosystem because of the essential (indispensable) good and services it provides (e.g., water, air).

Knowledge/learning value: Value accorded to the ecosystem because of the support it provides for the acquisition of new knowledge (e.g., airplanes exist because someone observed birds in flight).

Heritage value (or existence value): Non-use value simply connected to the fact that a heritage exists. Non-use values are defined as being values pertaining to the satisfaction of knowing that an asset or established fact exists. These values are often connected to respect for nature and notably serve to justify the protection of known species or natural sites.

Recreational value: Value derived from the use of the ecosystem for recreational purposes (e.g., hiking in the mountains, swimming in a river, bird watching).

Indirect socio-economic and cultural consequence

Cost: All the expenditures of an enterprise or sector of activity needed to carry out production or the economic activity. The price of goods and services offered by this enterprise or sector of activity is set in part on the basis of the costs incurred.

Directly affected industries

Capelin fishery: All activities (authorized or not) involving the harvest of capelin biomass in its natural environment, regardless of whether they are conducted in a targeted manner (commercial, recreational, or subsistence fisheries) or not (bycatch).

Fisheries – other species: All activities (authorized or not) involving the harvest of finfish (other than capelin), crustacean, or mollusc biomass in their natural environment, regardless of whether they are conducted in a targeted manner (commercial, recreational, or subsistence fisheries) or not (bycatch).

Capelin processing: All primary and further processing activities involving capelin.

Processing – other species: All primary and further processing activities involving finfish species (other than capelin), crustaceans, or molluscs.

Indirectly affected industries

Harbour infrastructure: All the shore facilities that make up a harbour (e.g., breakwater, wharves, dry docks, navigational locks, boat launching ramps), fixed equipment used for harbour operations (e.g., cranes, other handling gear, warehouses, maintenance shops, other buildings), and the other means of transportation connected to them (railroads, roads).

Human modulating factor

Governance: Networking by actors from a variety of public, private, and/or civic sectors and their participation in the process of overseeing, monitoring, and guiding various sectors of economic activity (e.g., fisheries, forestry, energy production) to ensure strategic decision-

making and to make sure they function properly. In practical terms, the governance process translates into the adoption of e.g., legislation, management measures, and strategies. Any modification in the governance process can have repercussions on the behaviour of economic actors (e.g., increase or decrease in demand, jobs, production).

Demography: Statistical and quantitative description of a human population (e.g., number, age structure, sex, birth rate, emigration rate) and its evolution in time and space as a function of the community's social, cultural, economic, and biological characteristics.

Appendix 6. Description of the stressors that could cause alterations in the coastal area.

The following descriptions apply specifically to the ecological model for spawning / larval retention area.

Shoreline modification

The global rise in temperatures caused by human activity affects variables associated with erosion. Milder winters are reducing sea-ice and land-ice production, which decreases shoreline protection during winter storms. Global warming also contributes to rising sea levels and an increase in storm frequency and severity (Bernatchez and Dubois 2004). These effects amplify the process of bank erosion and shoreline retreat. To limit the impact of erosion and the significant retreat of certain beaches and cliffs, some municipalities and shoreline owners have built protective structures (e.g., riprap, small wooden or concrete walls) or undertaken artificial beach nourishment, which is the process of adding material such as sand or gravel to a beach to restore it. However, these techniques alter natural coastal dynamics. Moreover, studies conducted between 1996 and 2006 by Savard et al. (2008) in the Sept-Îles region showed an 84% reduction in the width of beaches lining coastal segments that had been reinforced.

Man-made constructions intended to regulate watercourses or water bodies (e.g., hydroelectric dams, control dams, breakwaters) also have an impact on the riparian area. For example, the regulation of river flow reduces bank erosion downstream from structures during flooding, but also reduces the amount of sediment carried by the impounded river to the sea (the sediment regime) (Savard et al. 2008). Furthermore, the reduced flow of an impounded river allows storm waves to penetrate further inland, thereby intensifying shoreline erosion at river mouths (Lajoie et al. 2007). Thus, while erosion is a natural process, it can be accelerated by shoreline and watercourse artificialization.

Modification of the hydrological regime

Most freshwater inputs into the Estuary and Gulf of St. Lawrence come from its numerous watersheds (Dufour and Ouellet 2007). In the coming years, rising temperatures due to climate change will be one of the main causes of freshwater flow variation (Dufour and Ouellet 2007). Thus an increase of one degree Celsius globally should result in a 4% increase in precipitation (Labat et al. 2004). Climate models predict an increase in precipitation for all the watersheds of the Great Lakes and the Gulf of St. Lawrence. According to these models, summers should be drier, while winters should see more precipitation (IPCC 2001; cited in Dufour and Ouellet 2007). Climate change could also affect sea currents, mainly due to glacier melt. All these changes may influence predator–prey relationships (trophic relationships) by altering the primary production and migration of various marine species (Anderson and Möllmann 2004).

The modification of the St. Lawrence's hydrological regime (estuary and gulf) by human activities (primarily control structures) and climate change also influences the sediment regime, water temperature and salinity, organic matter and nutrient input, and ecosystem health (Pierson et al. 2002, Hudon and Carignan 2008). These modifications are explained in more detail in their respective sections. However, according to Bourgault and Koutitonsky (1999), variations in the hydrological regime caused by human activities are much less significant than those caused by nature. Yet, hydroelectric operations are designed to follow fluctuations in electricity demand,

which alters the natural hydrological regime considerably (Clarke et al. 2008). Even today, few studies fully assess the large-scale cumulative impacts of hydroelectric development. They usually focus on local impacts, overlooking coastal and marine systems that are often located several hundred kilometres downstream from the dam (Rosenberg et al. 2007). Hydroelectric dams and other control structures affect the volume and rate of river flow by controlling very high and very low flows, which reduces the amount of sediment transported by the current (Clarke et al. 2008). A decrease in grain size is also observed for the sediment that escapes the reservoir (Brandt 2000).

Modification in water temperature and/or salinity

Changes in water temperature or salinity can be explained by the effluents discharged from various sectors of human activity, but also by natural or artificial variations in freshwater inputs. Such fluctuations in environmental conditions can have major consequences on the distribution or biological parameters (such as rates of larval survival, egg hatching, or malformations) of certain species, such as capelin or its prey (Stergiou 1991, Frank et al. 1996, Jàkupsstovu and Reinert 2002, Bacon et al. 2005, Rose 2005, DFO 2008b). These changes will inevitably have repercussions on trophic relationships in the environment.

Municipal wastewater treatment plant effluents and surface runoff can be a source of thermal enhancement of receiving waters because they are usually warmer than the water bodies they empty into (EC 2001). Warm urban surfaces, such as roads and rooftops, add heat to rainwater as it runs off these surfaces and flows into storm sewers. Further warming may occur in runoff control facilities, particularly stormwater ponds with extended retention times (EC 2001). Schueler (1987) showed that, in summer months, stormwater pond effluent might be up to 10°C warmer than the inflow. The industrial activities sector may produce similar effects in the environment. Effluents from pulp and paper mills, aluminum smelters, and steelworks as well as fish processing plants increase water temperatures in receiving environments and modify salinity (Morry et al. 2003, EC 1998, 2003, 2005). Lastly, runoff from agricultural and forest land also modifies water temperature. Sediment particles in the soil absorb warmth from the sun. After it rains, sediment particles dislodged from the soil are suspended in the water, increasing the water temperature (EC 2008). Furthermore, rivers whose shorelines are devoid of vegetation will be more directly exposed to the sun. Consequently, their temperature will be higher.

The change in water temperature caused by a control structure, such as a dam, depends on a number of factors, including the physical characteristics of the watercourse, the size of the dam, the level of hydroelectric production, the reservoir's discharge period, and the origin of the reservoir water (upper or lower level) (Webb 1995). Variability in climate and annual energy demand require dam operation to be adjusted. This can cause pronounced interannual variations in the thermal regime of the water downstream from the dam (Webb and Walling 1996). The regulation of the flow of impounded rivers raises mean water temperature when the water comes from the top levels of the reservoir. Conversely, when the water comes from the lower levels of the reservoir, the opposite phenomenon is observed (Clarke et al. 2008). The effects of variations in the water temperature of impounded rivers can extend as far as 400 km downstream from the dam (Holden and Stalnaker 1975).

Modification in organic matter and/or nutrient input

Organic matter and nutrients from the soil are transported by water action (rain or snow melt). River water generally contains higher concentrations of nutrients than the surface waters of the ocean. It is therefore an important source of nutrients for estuary or coastal waters (Yeats 1988). According to Sutcliffe (1973), variations in freshwater input are strongly correlated with fish production in the Gulf of St. Lawrence, which implies that modifications in nutrient input due to changes in freshwater flow can be significant (Yeats 1988, MCI 2009a).

Constructions intended to regulate watercourses or water bodies have an impact on the hydrological regime, biochemical cycles, and the upstream–downstream transport of organic matter and nutrients. Dams alter water discharge (flow rate) throughout the year by alleviating the spring freshet. This new regime changes the volume and characteristics (such as particulate matter or nutrient salt loading) of the water flowing toward riparian aquatic environments (Dufour and Ouellet 2007). Reservoirs increase the sedimentation of suspended particles locally, withdrawing organic matter and nutrients from the river mouth as a consequence (Friedl and Wuest 2002), which affects the biological productivity of inshore areas (Clarke et al. 2008).

Organic matter and nutrient input into the environment can be increased by diverse human activities or actions. For example, loss of forest cover (deforestation) and its replacement by bare, hard, and impermeable surfaces promote erosion and, consequently, the increased transport of organic matter and nutrients into watercourses by leaching. For example, buildings, paved roads, and parking lots are all impermeable surfaces that alter hydrology by preventing water from infiltrating into the soil and conveying it rapidly to the hydrological system (EC 2001). Water that can no longer infiltrate into the soil flows over the surface, leaching and eroding any soil that is bare. According to the MCI (2009a), a bare construction site erodes 10 to 100 tonnes of soil per acre per year, which is the equivalent of an erosion rate 10 times greater than that of farmland, 200 times greater than that of pastureland, and 2000 times greater than the normal erosion rate of woodland. Roads and access roads that are poorly constructed or in poor condition are potential erosion sites. Poorly stabilized culverts or inadequate road surface thickness increase leaching, which increases the likelihood of the structure collapsing completely, causing large quantities of sediment to enter the aquatic ecosystems (MCI 2009a).

Forestry and agriculture activities also increase organic matter input locally. Logging activities and forest drainage alter the hydrology of the watershed (NRC 2008). Soil left unprotected by plant cover is more susceptible to erosion, which leads to increased transport of organic matter through runoff. Furthermore, the repeated passage of heavy machinery near watercourses can move significant quantities of sediment into the hydrological system (MCI 2009a). Organic (manure) or chemical (nitrogen, phosphorous, potassium, and a few trace elements) fertilizers used in agriculture that are not absorbed by land plants are transported by runoff and end up in the riparian area where they nourish aquatic plants (AAC 1998; MCI 2009b). During tillage, bare soil is susceptible to erosion because it is exposed to the action of water transporting organic matter and nutrients (AAC 1998). Studies have shown than an acre of agricultural soil on a gentle slope devoid of plant cover can allow up to 7 tonnes of soil to move into the hydrological system each year (MCI 2009a). If livestock are allowed free access to watercourses and their riparian strips, they trample the shoreline with their hooves, destroying vegetation and sending significant quantities of sediment into the hydrological system.

Harbour activities can return organic matter or nutrients in local sediment to circulation. After the ice run, increased marine activity causes sediment that has accumulated on the bottom to be resuspended, increasing turbidity (Misic and Covazzi Harriague 2009). Dredging activities also cause bottom sediments to be resuspended, releasing large quantities of nutrients and organic matter and increasing the turbidity of the environment (Kennish 1992).

The input of organic matter and nutrients from many sectors of human activity artificially enriches the local environment. Untreated or partially treated municipal wastewater discharged into watercourses, along with the absence of individual septic systems or poorly maintained ones, allows high loads of organic matter and nutrients, in particular phosphorous and nitrogen compounds, to be released into marine ecosystems (EC 2001, Colmenarejo et al. 2006, Dufour and Ouellet 2007, MCI 2009b). Effluents from the pulp and paper industry generally contain large amounts of organic matter particles composed of wood fibre and dissolved organic compounds, including resins and fatty acids (Hynynen et al. 2004, Bijan and Mohseni 2005). Fish and invertebrate processing plants use large amounts of water. Effluents from these plants discharge solid suspended matter, oils, microorganisms, organic matter, and nutrients into the environment (Carawan 1991, Morry et al. 2003, Islam et al. 2004). The discharge of liquid and organic waste from ships increases organic matter and nutrient input in harbours and marinas (Greig and Alexander 2009, Misic and Covazzi Harriague 2009). In aquaculture, organic matter and nutrients are introduced into the aquatic environment when uneaten fish feed and feces from cultivated organisms are deposited below rearing structures.

The consequences of this enrichment or impoverishment of coastal environments in organic matter or nutrients vary depending on local environmental conditions (e.g., current, topography). However, they will invariably have an impact on local biological production or the quality of the environment (for example, by silting beaches that are important for capelin spawning), which could then affect both capelin development and trophic relationships.

Introduction of contaminants

Many contaminants are introduced into the marine ecosystem by surface runoff, urban and industrial effluents, and by the atmosphere (in the form of gases or aerosols) (Dufour and Ouellet 2007). Contaminants are generally transported by suspended sediments bound to minerals or organic matter (Dufour and Ouellet 2007). Heavier particles are deposited close to their source, while smaller particles are carried over longer distances and deposited in places where the currents are weak (DFO 2003). Sedimentation and the remote effects of contaminants depend on source characteristics (the level of activity responsible for the introduction of the contaminant) and environmental conditions (e.g., water depth, current velocity) near the source (DFO 2003).

Many human activities introduce persistent and bioaccumulative contaminants into the environment. For example, a large quantity of metals (mercury, lead, cadmium, zinc, and iron) comes from urban effluents, industrial waste, dredging, and aquacultural and agricultural activities. They are found in the biota in their organic form and are therefore bioaccumulative (Stewart and White 2001). Pesticides, mainly from the agriculture and forestry industry, are released into surface runoff, which flows into coastal waters. According to Giroux (2004), after heavy rainfall, a higher number of different pesticides are found in surface runoff. Many pesticides (e.g., PCBs, DDT and its metabolites, mirex, toxaphene) are highly persistent

compounds that accumulate in sediments and organisms (Dufour and Ouellet 2007), as does tributyltin (TBT), found in antifouling paints.

Other contaminants, such as polycyclic aromatic hydrocarbons (PAHs), can come from natural sources, such as forest fires and natural gas leaks in the marine environment, but also from industrial activities (e.g., aluminum smelters, steelworks, oil facilities). These compounds are less persistent and bioaccumulative than persistent organic pollutants (POPs), but are nonetheless toxic to exposed organisms (Dufour and Ouellet 2007).

Appendix 7. Description of the potential impacts generated by alterations of the coastal area.

The following descriptions apply specifically to the ecological models.

Reduction in size of the intertidal zone

As a result of beach lowering and erosion, sandbars no longer remain adjacent to the coast but migrate in front of highly deficient beach areas. This phenomenon causes the beach to disappear (Savard et al. 2008). Furthermore, when the intertidal zone is characterized by a sand and silt substrate and has a negative sediment budget, stabilization structures can increase erosion and promote leaching of the zone down to the clay bed (Lajoie et al. 2007). Dredging, by moving or relocating bottom sediments, can also result in the destruction of potentially important capelin habitats (Kennish 1992). The disappearance or destruction of beaches—essential capelin spawning grounds—can have negative effects on capelin populations.

Erosion or sediment accumulation

Shoreline erosion results in habitat loss for capelin and other species (Lajoie et al. 2007). This natural phenomenon can be accentuated by diverse human activities. Coastal stabilization infrastructures, intended to protect the coast, increase sediment transport, which prevents the coastline from advancing and negatively affects the sediment budget (Savard et al. 2008). These infrastructures prevent the input of sediment from the upper beach, thereby depriving the intertidal zone of an important source of sediment. Similarly, hydroelectric dams, river flow regulation structures, and ice jam control, by reducing the rate and volume of river flow, interfere with beach nourishment from sediment and organic matter (Pierson et al. 2002, Lajoie et al. 2007, Clarke et al. 2008, Hudon and Carignan 2008, Savard et al. 2008). On the other hand, regulating river flow mitigates the phenomenon of bank erosion downstream from structures during flooding. However, the reduced sediment input and flow of an impounded river allow storm waves to penetrate further upstream and thus intensify shoreline erosion at river mouths (Lajoie et al. 2007). Furthermore, the repeated passage of pedestrians, all-terrain vehicles, and pick-up trucks along shorelines, for example for recreational fishing activities and fishing activities for food, social, and ceremonial (FSC) purposes, can damage vegetation, making substrate more available during storms and thereby contributing to the shoreline erosion process and beach loss (Lajoie et al. 2007).

Loss of substrate quality

Loss of substrate quality can alter substrate type (e.g., rock, sand, gravel, fine sediment), which is a determining factor in the selection of spawning sites by capelin. According to Nakashima and Taggart (2002), capelin select beaches for spawning according to, for example, sediment size structure (granulometry). Consequently, a change in sediment size can cause capelin to desert a beach. Various processes can explain the modification of a beach's grain size. For example, shoreline erosion, which is responsible for altering beach width, and artificial beach replenishment, which could contribute to altering substrate type, can lead to the loss of capelin spawning grounds (Lajoie et al. 2007). Hydroelectric dams and other control structures reduce the volume of flow of rivers and deprive the latter of severe flooding (volume, frequency, and duration), which changes the sediment deposition model downstream from the dam (Petts 1979).

Furthermore, dams trap a large quantity of organic matter and nutrients, which reduces a river's potential sediment input. These combined effects of control structures alter the granulometry of seabeds near river mouths (Clarke et al. 2008).

Variations in organic matter and nutrient input also affect substrate quality by changing not only grain size but also other substrate characteristics. For example, organic matter and soil nutrients from runoff from urban areas and the agriculture and forestry sector are transported by watercourses to inshore waters. When a soil particle is dislodged from its environment by water action, it becomes suspended matter. Soil nutrients, which are usually relatively insoluble, attach to these suspended particles and are transported by the water (MCI 2009a). In aquaculture, uneaten feed pellets and fish feces usually increase local concentrations of suspended and deposited particulate matter. The distances and locations of accumulations of suspended particulate matter are site specific and depend on bottom topography, currents, and erosion and flocculation processes that affect the residence time of the matter both in the water column (Sutherland et al. 2001) and on the bottom (Milligan and Loring 1997). In Danish inshore waters, Holmer (1991) collected matter directly attributable to a fish farm at distances of up to 1.2 km from the farm site. When a substantial layer of suspended matter is deposited on the bottom, it changes the grain size and quality of the substrate (MCI 2009a). The location of a salmon farm is believed to be responsible for the desertion of a spawning ground by a population of lobsters, probably owing to the alteration of bottom type to more fine-grained sediment through increased deposition of flocculated, fine-grained matter from uneaten feed pellets and fish feces (Lawton and Robichaud 1991).

Eutrophication due to the excessive input of nutrients and organic matter from urban and industrial (pulp and paper) effluents, fish processing plant effluents, and marine industry wastewater as well as dredging activities leads to anoxic conditions that alter substrate quality (Riegman 1995, EC 2003, Norring and Jorgensen 2009). The sediment of beaches located near a source of pollutants is generally contaminated (Lebeuf et al. 1999). Since most contaminants transported by suspended particulate matter are stored in sediment, this degrades substrate quality by making contaminants available to organisms. Consequently, capelin spawning habitat is exposed to contaminants, which can cause significant disruptions in its life cycle.

Silting

When a sufficient amount of sediment is deposited on a spawning site, it can smother eggs that are present and destroy the site's potential as a reproduction area for subsequent years (Parent and Brunel 1976, EC 2001, MCI 2009a). By reducing the survival rate of eggs, the silting of spawning grounds can have a serious impact on community structure. However, the deposition process takes time (Petts 1979), and wave action can reduce the deposition phenomenon and mitigate the silting effect (Moss et al. 2006).

The transport of organic matter and nutrients is a natural phenomenon that is not harmful to ecosystems provided it does not exceed the environment's assimilative capacity. However, certain land-use practices in urban planning, forestry, and agriculture, such as laying the soil bare, can lead to silting of aquatic ecosystems or even cause roads or culverts to collapse (Moss et al. 2006, MCI 2009a). Excess deposition of suspended matter from urban, industrial, and processing plant effluents, marine transport wastewater, dredging, and organic waste from the

aquaculture industry can also contribute to the sedimentation and silting of spawning grounds (Kennish 1992, EC 2001). Hydroelectric dams and other types of control structures also contribute to the spawning site silting phenomenon by increasing finer sediment loading in the environment (see previous section) (Pierson et al. 2002). More specifically, in the vicinity of the dam, flow management leads to bank erosion and leaching, whereas further downstream, decreased erosion is observed. The finer sediment load is transported and deposited along the river as far as the coastal area. It has been shown that this fine sediment can infiltrate into gravel, leading to loss of salmon spawning habitat (Nelson et al. 1987). If this fine sediment is transported as far as the coastal area, capelin beaches could be affected in the same way, which could significantly reduce spawning success (Nakashima and Taggart 2002).

Predator–prey relationship

Capelin is one of the most important forage species for maintaining the ecological balance of the St. Lawrence ecosystem. Over the last 20 years, it has been the main prey in the northern Gulf of St. Lawrence ecosystem (DFO 2005). Indeed, capelin is a link near the bottom of the food chain and transfers energy from primary and secondary producers, which it feeds on, to species in higher trophic levels, which prey on it. Capelin feed mainly on zooplankton (Jangaard 1974, Vesin et al. 1981, Savenkoff et al. 2009). Zooplankton abundance is therefore an important factor in controlling capelin year-class strength (Vesin et al. 1981). Moreover, fishing can strongly influence the abundance of capelin populations either directly, through fishing efforts that specifically target capelin, or indirectly, through fishing efforts that target its predators, which could lead to an increase in capelin populations (Worm and Myers 2003, Savenkoff et al. 2007a).

Environmental conditions can also affect, directly or indirectly, the abundance or availability of capelin, its prey, or its predators, thereby influencing predator–prey relationships. In spring, the massive influx of freshwater modifies the physicochemical properties of water masses and generates a stratification of the water layers. The slowing of the flow and velocity of the current leads to mixing between water layers and stimulates primary production (Dufour and Ouellet 2007). Modification of the hydrological regime could have an impact on the spring bloom of plankton and, consequently, on capelin that depends on zooplankton for food (Vesin et al. 1981). Furthermore, capelin appears to synchronize its larval dispersion to coincide with the presence of water masses characterized by an abundance of food and few predators. These water mass conditions favourable to larval growth are caused by coastal wind action (Frank and Leggett 1983). If larvae hatch during periods that are not conducive to their growth, they are more available for predation (Frank and Leggett 1981a). Thus, when winds are low or absent, larval dispersion could be delayed, which would lead to a deterioration in the physiological condition of capelin larvae and render them less able to avoid predators.

The modification of water column temperature can also change the community make-up or distribution of capelin when thermal limits are reached. This can lead to the modification of predation and competition dynamics (Smith 1972). Davoren et al. (2006) have reported that in the Newfoundland region in spring, adult capelin, whose gonads are maturing in preparation for spawning, aggregate along the coast. They move to warm surface water (> 0°C) during hours of darkness and remain in cold deep water (< 0°C) during daylight. These daily movement patterns may reflect a compromise between growth and survival. Furthermore, Mowbray (2002) suggests that vertical dispersion of adult capelin reduces predation risk. Cold, deep water reduces

predation risk from visual, air-breathing predators, while warm, surface water allows increased gonadal development (Davoren et al. 2006). Jorgensen et al. (2004) point out, however, that the pressure of natural selection relating to capelin might encourage it to concentrate more on feeding and reproduction than on predator avoidance.

Urban and industrial (pulp and paper) effluents and those from fish processing plants, runoff from the forestry and agriculture industry, waste from the marine and aquaculture industry, and dredging activities discharge excess quantities of organic matter and nutrients into the environment and introduce diverse contaminants locally. The adverse effects of contaminants on fish affect their overall health. Fish with atrophied fins or affected by diseases are easier prey. Adult fish can transfer part of their toxic load to eggs. Larvae and juveniles affected by toxin either via their parents or their environment can, in turn, develop abnormalities and become more vulnerable to predators. Moreover, the artificial increase in sediment loads leads to increased turbidity in the environment, that is, it enriches surface water with particulate matter and modifies the amount of light penetration. Turbid water can affect the organisms present negatively or positively. Firstly, the amount of light that penetrates the water column is a limiting factor for primary production. Yet, it influences the production of zooplankton, the availability of which is critical for fish larvae survival (Levasseur 1996). Secondly, the absence of light and lack of visibility have a significant impact on feeding, even when food is abundant, since many aquatic predators rely on their vision to feed (Drolet et al. 1991, Gilbert et al. 1992). In some cases, very turbid water can provide protection from predators, which offsets the negative aspects of feeding in such environments and helps sustain a certain growth rate for these organisms (Sirois and Dodson 2000). Thirdly, overloading the environment with organic matter and nutrients can lead to degradation of the environment and habitat loss for numerous organisms. Hence, this excessive input can influence the quantity of zooplankton available for capelin feeding (Riegman 1995).

In contrast to the above-mentioned activities, hydroelectric dams and other control structures reduce the amount of organic matter and nutrients discharged into the hydrological system which, similar to very turbid water, adversely affects primary production (Clarke et al. 2008). Following the construction of a dam in British Columbia, Ashley et al. (1997) observed a decrease in phosphorous input in both tributaries of the impounded river. The results of the study show that this decrease caused a decline in phytoplankton and zooplankton production, which negatively affected salmon catches.

In addition to adding substantially to organic matter and nutrient loads locally, as mentioned previously, the aquaculture industry can represent an additional predator for capelin. Bivalve culture plays an important role in nutrient cycling in coastal ecosystems, since the nutrients stored in the cultured biomass are not available to the marine food web (DFO 2003). Furthermore, ingestion of phytoplankton by bivalves reduces phytoplankton abundance in the vicinity of bivalve culture operations (Horsted et al. 1988, Davenport et al. 2000). In the Great Lakes, studies have shown that bivalves compete with zooplankton for algae, which affects zooplankton production and has repercussions on the diet of fish that feed on it (EC 1996).

Reproduction
The sexual maturation, spawning times, and spawning site selection of capelin are influenced by temperature conditions in the environment (Carscadden et al. 1997, Nakashima and Wheeler 2002, Grégoire 2004). In late winter and spring, capelin gonads reach maturity (Carscadden et al. 1997). The energy devoted to gonad maturation reduces fat percentage. An inadequate percentage of fat can reduce gonad maturation rate and have a negative impact on reproduction (Orlova et al. 2006). To offset this phenomenon, feeding intensity increases, which maintains the percentage of fat (Jangaard 1974). However, the availability of capelin prey is influenced by water temperature. This can therefore affect the quantity of fat, which is necessary for reproductive success.

Capelin spawning occurs in June and July on the beaches of the east coast of Newfoundland and Labrador. In these locations, capelin prefers water temperatures ranging from 5.5 to 8.5°C for spawning. However, spawning has been observed at temperatures as high as 10°C (Jangaard 1974) and other research has reported a wider range of temperatures, 2.5 to 10.8°C (Frank and Leggett 1981a). Nevertheless, Nakashima and Wheeler (2002) observed that along the coasts of Newfoundland, spawning ceases when water temperatures exceed 12°C. When the temperature of the water column changes, the spawning period may change. During the 1990s, cooler water temperatures were recorded on Newfoundland's east coast. These cooler temperatures are thought to be responsible for the delay observed in gonadal maturation, but also in capelin spawning times (Nakashima 1996). When spawning is delayed, mature capelin lengths and weights are lower (Carscadden 1978).

It has been suggested that capelin maturation and migration are closely linked to spring warming and the cycle of zooplankton, its main prey. Thus, better knowledge of spring water temperatures would permit some prediction of capelin spawning time. Indeed, a combination of increased mean capelin length and warmer pre-spawning water temperatures is believed to be associated with earlier spawning times and, conversely, spawning is believed to be delayed if capelin are smaller and water temperatures are cooler (Carscadden 1978, Nakashima 1996, Carscadden et al. 1997). Also, smaller mature capelin will produce fewer eggs, since fecundity is related to fish length (Nakashima 1987), which could have an impact on capelin abundance. However, if spawning is delayed and capelin spawns in summer (July and August), water temperatures will be warmer and the negative consequences associated with spawning would be reduced (Nakashima and Wheeler 2002).

Spawning takes place on beaches in shallow water. Contamination of spawning grounds by pollutants can expose spawners to high concentrations of contaminants (acute toxicity) and lead to mortality. The exposure of adult fish to sublethal concentrations of contaminants can have diverse effects, but few studies have been conducted in the natural environment on contaminants and their effects on organisms. Furthermore, during the spawning season, capelin migrates and aggregate. If these behaviours are compromised as a result of exposure to pollutants, a decrease in reproductive success would be expected.

Chemical contaminants from wastewater can affect reproductive function in male fish (endocrine disruption) (EC 2007). Endocrine disruption creates an imbalance in the hormonal system that can result in delayed gonad maturation, thereby affecting reproduction. In many fish species exposed to pulp and paper mill effluents, decreased gonad size, altered expression of secondary

sexual characteristics, and decreased fecundity have been reported (Hewitt et al. 2008). Some contaminants can also be transferred. Rainbow trout exposed to PCBs transferred contaminants to their eggs (Niimi 1983). PCBs in eggs reduce their survival rate as well as that of larvae. Niimi (1983) showed that the percentage of lipids in fish and the total percentage of lipids in eggs can influence the transfer of contaminants from fish to eggs. Immune function can also be compromised, leaving fish more vulnerable to infestations by parasites and infectious diseases (Khan and Thulin 1991), which can influence reproduction by decreasing spawner numbers. TBT in antifouling paint is highly immunotoxic for all aquatic species and is also an endocrine disrupter (Pelletier 2009). Chronic toxic effects such as tissue damage and neurotoxic and hepatotoxic effects have also been associated with exposure to TBT (Fent 2006). Fish contaminated with TBT can experience difficulties reaching spawning grounds due to behaviour and mobility problems. Pesticides used in agriculture and forestry, such as atrazine and diazinon, can also have effects on swimming activities, aggregation behaviour, the immune system, and reproductive success (Niimi 1983, Giroux 2004, DFO 2007b). The exposure of adult fish to hydrocarbons can influence their rate of survival, growth, respiratory and heart rate, fin erosion, and reproduction (Greig and Alexander 2009). According to Couillard (Catherine Couillard, DFO, pers. comm.) eroded fins grow back but are less efficient, which reduces fish mobility during migration and can affect their reproductive success.

Reduction of spawners

The spawning stock is composed almost exclusively of three- and four-year-old fish (Grégoire 2004), whose ratio varies naturally from year to year (Jangaard 1974). By first selecting individuals that are bigger and faster growing, fisheries create an artificial selective pressure that generates adaptive responses from the stock (Dufour and Ouellet 2007). For example, for heavily fished Barents Sea capelin, recruitment relies on slow-growing individuals that reach sexual maturity at an earlier age and smaller size (Terenschenko 2002). This adaptation increases the chances of reproducing before being caught. However, according to Terenschenko (2002), smaller, younger spawners are causing a significant decline in fecundity, and this effect is amplified by unfavourable environmental conditions.

Since capelin spawning stock is composed of only a few age classes and fluctuations in capelin abundance are closely linked to fluctuations in recruitment and environmental conditions (Grégoire et al. 2003), a significant fishing effort combined with a low recruitment year could have a negative impact on population size and result in the disappearance of a large portion of the spawning stock (Jennings and Kaiser 1998).

Size of individuals

Mean capelin length in the spawning grounds varies depending on the dominant year class, namely, three-, four-, or five-year-old fish. Individual capelin size varies with the seasons and the years. As mentioned previously, food availability and water temperature can have a significant impact on mature specimen size (Jangaard 1974, Carscadden et al. 1997). Since the mid-1980s, as a result of colder water temperatures in the cold intermediate layer of the Gulf of St. Lawrence, a steady decrease in mean capelin size has been observed. As a result, the fishery was closed rapidly in 1994 and almost completely halted in 1995. While capelin size has been increasing since 1999, the values measured in 2002 remain below those observed in the 1980s

(Grégoire 2004). It was not until 2005 that capelin regained a mean size similar to that of the late 1980s, namely, 152 mm for females and 170 mm for males (DFO 2005).

Egg hatch

The duration of egg incubation is strongly influenced by water temperature. As demonstrated by Jeffers (1931) (cited in Jangaard 1974), hatching takes place in 55 days at 0°C, in 30 days at 5°C, and in 15 days at 10°C. Mean incubation temperatures are determined by a range of variables, including water temperature, maximum and minimum air temperature, and hours of sunlight (Fortier et al. 1987, Frank and Leggett 1981b).

Exposure of eggs to high concentrations of contaminants leads to embryo death (Walker and Peterson 1991). Exposure of eggs to sublethal concentrations of contaminants such as organochlorine compounds (e.g., PCBs, dioxins, furans) can reduce hatching percentage or cause abnormalities in embryos (Hogan and Brauhn 1975, Zitco and Saunders 1979). PAHs can also impair embryo development and cause serious abnormalities in the form of malformations (teratogenic effects) and mutations (genotoxic effects) (Couillard 2002, Greig and Alexander 2009). The *Exxon Valdez* spill in Alaska covered the intertidal zone with fuel oil and affected the spawning grounds of herring and other fish (Peterson 1989). Following the spill, a reduction in the abundance and biomass of fish in the intertidal zone was observed.

Larval survival

Pre-emergent capelin larvae leave the sand where they were buried and enter a pelagic environment (emerging larvae). They are then rapidly and passively transported by warmer water masses to the open sea where they will grow and feed (Jaangard 1974). Frank and Leggett (1983) noted that larval emergence and survival are regulated by water temperature and coastal winds. Since there is little food for larvae in sediment, they must leave the beach before they deplete their yolk-sac reserves. Otherwise, their condition would deteriorate rapidly (Frank and Leggett 1981a). Wind-induced wave action causes larvae to emerge from the substrate. It increases water temperatures, which stimulates larval activity, thereby facilitating the pelagic stage of the capelin (Frank and Leggett 1981a). Coastal winds are favourable to the formation of water masses characterized by an abundance of food and few predators, thereby creating conditions favourable to their survival (Frank and Leggett 1983). When water temperatures are colder, larvae emerge later in August and September and may encounter conditions that are less favourable to their survival or growth, such as the absence of coastal winds which usually increase water temperatures (Frank and Leggett 1983). Furthermore, colder water temperatures can reduce larval growth and affect their transformation from the larval to the juvenile stage (Clarkson and Childs 2000) or have indirect effects by influencing the production of food available for capelin larvae. This indirect effect could take the form of an increased mortality rate due to starvation or a modification in growth rate, which would influence swimming performance, predator avoidance, and pre-metamorphosis time (Leggett et al. 1984).

Exposure of fish larvae to high concentrations of contaminants results in their death, while exposure to sublethal concentrations can lead to physiological abnormalities. TBT has embryotoxic and androgenic effects in fish. McAllister and Kim (2004) showed that early life exposure to TBT caused masculinization (male-biased sex ratio) and irreversible sperm damage in zebrafish (*Danio rerio*). Fish larvae are also very sensitive to PAHs. Newly hatched larvae

exposed to PAHs exhibit multiple abnormalities (Peterson 1989). Samples collected after the *Exxon Valdez* oil spill showed that larval mortality rates were much higher and their growth delayed in areas contaminated by fuel oil.

Malformations

If water temperatures are too high, embryo development can be halted or impaired, which tends to increase egg mortality (Nakashima and Wheeler 2002). Similarly, water temperatures that are too cold can result in embryo deformity and even death (Clarke et al. 2008). Exposure to contaminants can also cause malformations. Fish are sensitive to high concentrations of metals in the water. Some metals, such as lead and cadmium, affect membrane and muscle structures and cause bone deformities (Mance 1987, Sorenson 1991), while chlorine compounds can cause vertebral malformations or fin erosion (Couillard and Nellis 1999).

Eutrophication

Eutrophication is a process of water enrichment that can be divided into four successive stages: (i) the continuous excessive input of organic waste and nutrients (MCI 2009a, Dufour and Ouellet 2007), (ii) the proliferation of algae (phytoplankton and macroalgae), (iii) anaerobic decomposition, and (iv) extreme environmental degradation (Menesguen et al. 2001). Higher water temperatures can accelerate the eutrophication of water bodies (Malham et al. 2008).

Urban and industrial effluents and those from fish processing plants, runoff from the forestry and agriculture industry, organic waste from the marine and aquaculture industry discharged into coastal waters and dredging activities can lead to organic matter and nutrient overloading, thereby contributing to the eutrophication of inshore waters (Kennish 1992, Slepukhina et al. 1996, Chambers et al. 1997, Merilainen et al. 2000, Stewart and White 2001, DFO 2003, EC 2003, Morry et al. 2003, Hynynen et al. 2004, Islam et al. 2004, Colmenarejo et al. 2006, NRC 2008, Misic and Covazzi Harriague 2009, Norring and Jorgensen 2009). The effects of the discharge of organic matter and nutrients from these sources are usually local (Stewart and White 2001). The degree of enrichment depends on a number of factors: source size, local hydrographic characteristics, water depth, and certain biological processes, such as absorption by phytoplankton or recycling (DFO 2003).

Excessive organic matter and nutrient input stimulates phytoplankton (Menesguen et al. 2001) and macroalgal growth. By colonizing the environment, phytoplankton reduce water transparency and modify its physicochemical properties (MCI 2009a). At the end of their life cycle, phytoplankton settle on the bottom, adding to the amount of organic matter to be degraded. Their degradation and the excessive and rapid development of microalgae reduce the amount of oxygen dissolved in the water, in particular near the bottom (Hynynen et al. 2004). The proliferation of macroalgae and stringy algae in the intertidal zone can affect the spawning grounds and diet of benthic and fish communities by colonising and modifying the environment (Riegman 1995). In short, the excessive growth of algae and the resultant significant reduction in oxygen can lead to major changes in the benthic ecosystem: the reduction of biodiversity and the appearance of species that are more tolerant of low oxygen levels, the migration of fish and invertebrates towards better oxygenated sites, and, lastly, the modification of trophic relationships in the environment (Islam et al. 2004, Dufour and Ouellet 2007, MCI 2009a, Pelletier 2009).

Oxygen depletion leads to the anaerobic (in the absence of oxygen) decomposition of organic waste and degradation of proteins and other nitrogen compounds, releasing gases such as hydrogen sulphide, ammonia, and methane (Islam et al. 2004). These products are potentially dangerous for the ecosystem and toxic to marine organisms in low concentrations. A high oxygen deficit can also adversely affect the embryonic and larval development of organisms that live in this environment by limiting the nursery functions of spawning and larval retention areas (Person-Le Ruyet 1986). In the Bay of Vilaine (France), anoxic conditions in the nursery area resulted in delayed growth in young sole (Koutsikopoulos et al. 1989).

The effects of eutrophication can extend to coastal or intertidal zones. Intertidal zones, subject to daily movements of water and sediment caused in large part by the tides, are influenced by large-scale processes affecting fluxes of particulate and dissolved matter (DFO 2003). In the St. Lawrence Estuary, the phenomenon of eutrophication can occur locally in bays where currents are weak and where industrial and urban wastewater or wastewater from other human activities is discharged. Around Prince Edward Island, the excessive input of agricultural fertilizer has led to eutrophication of coastal waters, resulting in oxygen depletion and a reduction in habitat productivity (DFO 2003, Dufour and Ouellet 2007). However, these sites are relatively rare owing to the local topography, low population density, and rapid water circulation in the estuary, which cancels out the effects of nutrient enrichment from local or upstream sources (EC 1996).

Toxicity

The toxicity of a contaminant is defined as its potential to have negative effects on the health of organisms in the short, medium, or long term (Giroux 2004). The effects observed depend on the degree of toxicity of the product and the frequency and conditions of exposure. The toxicity of contaminants therefore varies from one product to another.

Different types of toxicity are defined according to exposure. Acute toxicity is associated with a short period of exposure (from a few hours to a few days) to generally high concentrations of a chemical product (Ramade 1979). This type of toxicity can lead to the loss of vital functions and death. Acute intoxications of organisms often result from an accidental discharge of contaminants. Chronic toxicity can be defined as the sum of effects observed after medium- to long-term exposure to a contaminant. Longer-term toxic effects observed are the degradation of the general health of organisms and disruptions in their life cycles. This type of toxicity is frequently observed in the natural environment (Dufour and Ouellet 2007).

The effects of contaminants also vary according to the species affected, the level of contamination (toxic load) of the organism, and the distance from the contaminant source (Dufour and Ouellet 2007). For persistent compounds (many pesticides, PCBs, DDT), the toxic load is generally proportional to the degree of exposure and the organism's trophic level, and varies according to individual stage of development. To date, few studies have focussed specifically on capelin and the different contaminants that can affect it. However, the capelin's relatively short life cycle (4 or 5 years) as well as its low trophic level and pelagic lifestyle are such that it is less exposed to contaminants than sedentary species living in the coastal area.

In general, the toxicological effects of contaminants on fish populations are little known. Each class of chemical contaminants identified could be the object of a separate detailed study. There is a serious lack of data on the cumulative effects of exposure to chemical products and the effects of exposure to multiple contaminants on organisms. However, some contaminants, such as TBT, are better known. TBT and its derivatives are toxic to marine organisms and can damage certain organs and hormonal systems. Just a few hundred nanograms of TBT per litre of water are enough to cause acute toxic effects in invertebrate and plankton species, while just a few milligrams per litre of water are enough to cause an acute toxic reaction in fish. TBT also induces neurotoxic, embryotoxic, hepatotoxic, and androgenic effects in fish (Fent 1996, 2006).

Bioaccumulation

Bioaccumulation occurs when a marine organism cannot metabolize the entire load of an absorbed contaminant and the contaminant then accumulates in tissues. When contaminants are transferred to higher trophic levels through predation, they accumulate even more, which is termed biomagnification. PCBs and other organochlorine contaminants are good examples of contaminants that bioaccumulate in marine organisms and are found at all levels of the food chain. Lebeuf et al. (1999) showed that, although occurring at concentrations well below Canadian guidelines for the protection of human health, PCBs and organochlorine pesticides accumulate in cod, American plaice, and Greenland halibut found in the northern Gulf of St. Lawrence.

In capelin, the bioaccumulation cycle is as follows: (i) contaminants accumulate in sediment, (ii) when filtering water to feed, zooplankton ingest fine sediment particles that contain contaminants, (iii) they then excrete the sediment, but the contaminants accumulate in their bodies, (iv) capelin, which prey mainly on zooplankton, ingest these contaminants, which then accumulate in capelin.

Appendix 8. Example of additional information for the specific ecological model for the spawning / larval retention area.

The Appendix 8a presents an overview of the different issues identified for capelin conservation in connection with alterations of the coastal area. The interest of this appendix lies primarily in the direct connection that it serves to make between human activities and the stressors they generate. This information is particularly shown in the holistic model (Figure 3) and the specific ecological model for spawning / larval retention area (Figure 4). However, the direct connections between an activity and the stressors, as shown in the Appendix 8a, are not shown directly in those figures. It would be possible to show this information in a PoE model diagram, but this would require the creation of a new model or would add much greater detail to the existing model (the above-mentioned ecological model), which would make it even more complex.

Additional information could also be included and transferred in PoE format. For instance, Appendix 8b shows an example of more detailed information for the *Introduction of contaminants* stressor. It shows that it would be possible to subdivide impacts into several sub-impacts. This new information, which has an even higher degree of detail, could be reproduced in PoE format.

Annexe 8a. Overview of the issues affecting capelin conservation in the study area and the relationships existing between the potential activities, sub-activities and stressors.

Activities	Sub-activities	Stressors					
		Shoreline modification	Modif. of hydrological regime	Modif. of water temperature and/or salinity	Modif. in nutrient input	Modif. in org.matter input	Introduction of contaminants
Hydroelectric power generation and water management	Dams/deviations	X	X	X	X	X	
Municipal activities	Residential activities	X	X	X	X	X	X
	Road networks	X	X	X	X	X	X
Recreation and tourism activities	Golf and maintained green spaces	X			X	X	X
	Pleasure boating	X	X				
	Motorized vehicles	X					X
	Recreational fishing	X					
	Outings (e.g., hiking, cycling)	X					
Heavy industries	Steel foundries	X	X	X	X	X	X
	Aluminum foundries	X	X	X	X	X	X
	Pulp and paper mills	X	X	X	X	X	X
Maritime transport	Transportation of passengers or merchandise	X	X	X	X		X
	Harbour infrastructure	X	X	X	X	X	X
Aquaculture	Open-water infrastructure	X	X		X	X	X
	Land-based facilities	X		X	X	X	X
Road transport	Transportation of merchandise	X					X
	Road infrastructure	X	X			X	X
Oil and gas	Seismic surveys						
	Exploratory drilling				X	X	
	Extraction	X					X
Fisheries	FSC fishing						X
	Commercial capelin fishing						X
	Bycatch						X
	Processing plants	X	X	X	X	X	
Forestry			X	X	X	X	
Agriculture			X	X	X	X	X

Annexe 8a. Overview of the issues affecting capelin conservation in the study area and the relationships existing between the potential activities, sub-activities and stressors.

Activities	Sub-activities	Stressors: Shoreline modification	Modif. of hydrological regime	Modif. of water temperature and/or salinity	Modif. in nutrient input	Modif. in org.matter input	Introduction of contaminants
Hydroelectric power generation and water management	Dams/deviations	X	X	X	X	X	
Municipal activities	Residential activities	X	X	X	X	X	X
	Road networks	X	X	X	X	X	X
Recreation and tourism activities	Golf and maintained green spaces	X			X	X	X
	Pleasure boating	X	X				
	Motorized vehicles	X					X
	Recreational fishing	X					
	Outings (e.g., hiking, cycling)	X					
Heavy industries	Steel foundries	X	X	X	X	X	X
	Aluminum foundries	X	X	X	X	X	X
	Pulp and paper mills	X	X	X	X	X	X
Maritime transport	Transportation of passengers or merchandise	X	X	X	X		X
	Harbour infrastructure	X	X	X	X	X	X
Aquaculture	Open-water infrastructure	X	X		X	X	X
	Land-based facilities	X		X	X	X	X
Road transport	Transportation of merchandise	X					X
	Road infrastructure	X	X			X	X
Oil and gas	Seismic surveys						
	Exploratory drilling				X	X	
	Extraction	X					X
Fisheries	FSC fishing						X
	Commercial capelin fishing						X
	Bycatch						X
	Processing plants	X	X	X	X	X	
Forestry			X	X	X	X	
Agriculture			X	X	X	X	X

Annexe 8b. Synthesis of human activities, sources of contamination, and the potential effects of contaminants on aquatic organisms inhabiting the Estuary and Gulf of St. Lawrence.

Human activity	Contaminant	Potential effects
Municipal activities	- Wastewater, waste snow, and run-off: DBT, pharmaceutical molecules(estrogens and hormones), pesticides, metals, salt (Na)	- Disturbance of immune system - Disturbance of endocrine system
Heavy industries	- Steel foundries: PAH, metals - Aluminum foundries: PAH - Pulp and paper mills: organochlorine contaminants (PCDD/F, PCB, dioxins, furans, and others), mercury	- Reduction in gonad size - Modification of secondary sexual characteristics - Reduction in the number of eggs laid - Vertebral malformation and fin erosion - Embryotoxic and immunotoxic effects - Modification of the reproductive cycle
Maritime transportation	- Marine transportation: ballast water (PAH), anti-fouling paint (TBT), accidental spills (PAH). - Harbour infrastructure: dredging (metals: Hg, Cd, Pb), old wharves (PAH)	- Neurotoxic, embryotoxic, hepatotoxic, androgenic, and immunotoxic effects - Disturbance of endocrine system - Powerful biocide
Aquaculture	- Antibiotics and medications used in fish feed - Pesticides - Anti-fouling agents used on nets: copper - Cage materials (metals): Cd, Pb, Cu, Zn, Hg) - Fish feed - Disinfectants: composed of chlorine	- Immunotoxic, genotoxic, and neurotoxic effects - Disturbance of endocrine system - Bony malformations
Road transportation	- Truck transportation industry: accidental spills of contaminants	- The effects depend on the nature of the contaminants.
Oil and gas	- Extraction and accidental spills: PAH	- Effects on survival and growth - Effects on reproduction; embryotoxic effects
Forestry	- Pesticides: tebufenozid, organochlorine contaminants (DDT, toxaphene, atrazine, others), diazinon, PAH (appears following forest fires)	- Effects on reproduction; embryotoxic effects - Disturbance of endocrine and immune systems - Effects on swimming activity - Effects on schooling behaviour
Agriculture	- Pesticides (insecticides, herbicides and fungicides), organochlorine contaminants (i.e., DDT, toxaphene, metolachlor, atrazine), diazinon	- Effects on reproduction; embryotoxic effects - Disturbance of endocrine and immune systems - Effects on swimming activity - Effects on schooling behaviour